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Nos. 18 & 20

Utilization of Indian Vegetable Oils as Lubricants in Internal Combustion Engines

(Revised Edition)

COUNCIL OF SCIENTIFIC & INDUSTRIAL RESEARCH
NEW DELHI
1953

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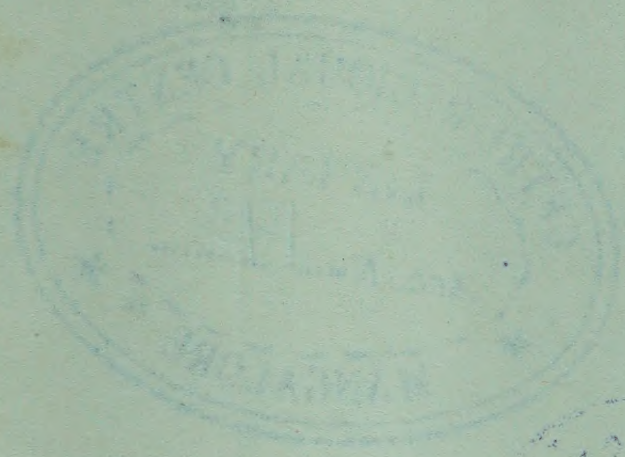
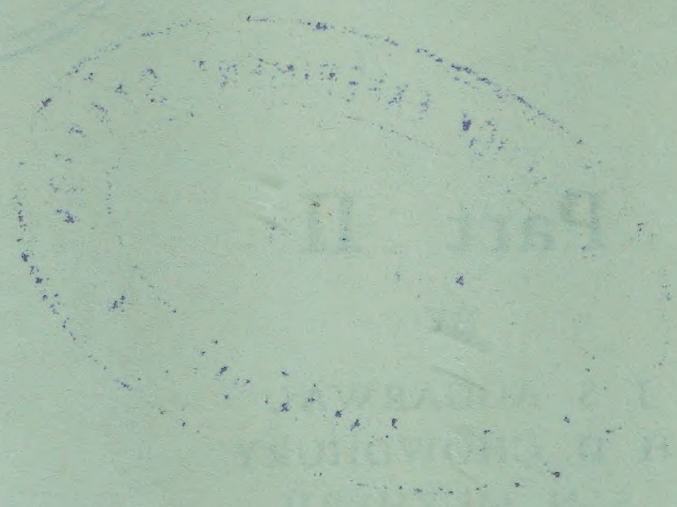
Part I





Preface

This publication is divided into two parts. Part I is devoted mainly to a discussion of the previous work in the field, the factors which contribute to the successful utilization of vegetable oils as lubricants, and oxidation stability and other characteristics of different vegetable oils or their blends with or without the addition of stabilizers. Part II deals with the results of engine trials using vegetable oil blends. The publication includes also statistical information and an appendix containing abstracts of papers on the use of vegetable oils as lubricants in internal combustion engines, published since 1942.

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Utilization of Indian Vegetable Oils as Lubricants in Internal Combustion Engines

Part I

Introduction

The employment of internal combustion engines for purposes of traffic and transport is rapidly increasing in almost every part of the world. Along with the development of engines to suit various requirements, numerous researches are in progress which aim at the production of lubricants most suited for their efficient performance.

Mineral oils have long been used as lubricants for internal combustion engines. Compared with certain other countries, India produces relatively small quantities of mineral oils (about 67 million gallons) which represent only 0.1 per cent of the total crude oil production of the world. This output is quite inadequate for the needs of the country, as may be judged from the import figures given in Table 1.

TABLE 1—Import of mineral lubricating oils (other than batching oils) into India

	Qty (gallons)	Value (Rs.)
1934-35/1938-39 (av.)	13,570,670	1,25,89,028
1939-40/1943-44 (av.)	20 887,816	3,00,97,582
1944-45	20,260,251	4,44,60,090
1945-46	24,261,906	5,07,51,822
1946-47	23,481,676	3,99,65,482
1947-48	39 116,355	7,07,04,219
1948-49	42,844,432	7,87,28,944
1949-50	39,524,027	6,94,19,495
1950-51	26,838,274	6,07,03,470
1951-52	33,981,826	9,77,76,530

The mineral oil resources of the world, though of large dimensions, are not evenly distributed. It is also believed that the world's mineral oil reserves cannot indefinitely cope with the ever increasing demand for lubricating oils and that a shortage will make itself felt in course of time. It is not surprising, therefore, to find that serious efforts are being made in several countries to find suitable substitutes for mineral lubricating oils.

One of the obvious solutions that presents itself is to use vegetable oils as lubricants. In India, the production of oil seeds, such as castor, sesame, rape, mustard, groundnut, cottonseed, linseed, mohua and niger, even at a conservative estimate, exceeds 5 million tons which is worth about 205 crores of rupees. The approximate annual production (in thousand tons) of oil seed crop (in terms of

oil equivalent) in the principal producing countries according to the statistics (1949) available is as follows: China, 3,354; United States of America, 2,523; India, 1,869; U.S.S.R., 980 (unofficial estimate); Argentina, 573; Brazil, 263; and British West Africa, 660.

India being one of the major oil seed producers is naturally interested in finding new fields of application for this commodity.

The results of investigations carried out with a view to develop internal combustion engine lubricants based on vegetable oils are reported in this part.

In the working of an internal combustion engine, the lubricating oil serves a two-fold purpose, namely, lubrication and heat dissipation. Consequently, the most important requirements of lubricants for internal combustion engines include chemical stability under working conditions, a high degree of oiliness, and a low co-efficient of static friction. In the latter two respects vegetable oils have been found to be better than mineral lubricating oils[1, 2, 3, 4]. Furthermore, a lubricating oil is required in an internal combustion engine to perform its functions over a wide range of temperature. It is important, therefore, that the viscosity of the oil should change as little as possible with changes in temperature. In other words, the "viscosity index" of the oil should be high. In this respect also, vegetable oils in general compare favourably with mineral oils [5, 6, 7]. Castor oil is regarded as one of the best lubricants known [8] and has in the past been employed on a considerable scale in aeroplane engines[9, 10, 11].

Rene Chefneux [12] prepared an oil for internal combustion engines containing 50-96 per cent castor oil, with which were incorporated colloidal graphite to increase the lubricating quality and tallow and corn oil, to suppress the odour and reduce the viscosity.

Various patents have been taken out dealing with the solubilization of castor oil in mineral oils so as to increase the viscosity and lubricating power of the latter[13, 14, 15]. Villiers[16] patented a process for using castor oil as lubricant after mixing it with a small proportion of alkali soap to increase its viscosity and reduce its susceptibility to carbonization.

Champsaur[6,17], in a discussion on the merits of vegetable oils—particularly olive, colza and peanut oils—for the lubrication of aeroplane and automobile engines under working conditions, stated that engines developed more power with such oils than with mineral oils.

Bastet [18], by comparative bench tests, found that olive oil, though more unstable both physically and chemically than mineral oils, when used as lubricant resulted in an increase in power of more than 10 per cent and an appreciable decrease in wear of the engine, but that in order to guard against the effects of the development

of acidity, sludge, and corrosion it was necessary to change the oil at short intervals. For similar reasons olive oil has also been recommended by Devez [19], Angla [20] and Condelli [21]. Methods of increasing the viscosity of rape seed oil for use in the production of mixed mineral oil blends[22, 23, 24], have been patented, and linseed oil[25] and neatsfoot oil[26] have also been recommended for the purpose.

It is important that lubricating oils should alter as little as possible in use, not only from the point of view of economy and convenience but also for certain technical reasons. For example, an oil requiring frequent changes is liable to form deposits, the effect of which is to choke oil feeds and thus, by preventing free lubrication, to cause breakdown, rapid wear, or ring sticking. Some of these defects were observed by Tomasi [51], when an automobile was run on crude olive oil. The cylinder and the piston are the two principal parts where the oil may suffer both physical and chemical changes on account of the high temperatures (200°-400°C.)[27, 29] prevailing at these parts as at temperatures of this order the cracking of the oil can easily occur.

Vegetable oils have, in general, a lower cracking temperature than mineral oils; for instance, castor oil decomposes at about 250°C. and olive oil at 310°C., while mineral oil decomposes at about 380°C.[28]. Weiss and Maillard[29] have come to the conclusion that pyrolysis, although occurring to some extent in the combustion chamber, does not play an important part in the alteration of the oil, at any rate not in an engine of ordinary design.

Deterioration of oil is mainly caused by oxidation, the most dangerous products being sludge constituents insoluble in hot oil. It is now generally accepted that the origin of the sludge is the lubricating oil and not the fuel. Incomplete combustion products of the fuel, however, may in some cases be found in the oil. From the sludge, it has been possible to isolate substances such as aldehydes and phenols which are capable of forming resins; moreover, vegetable oils, on account of their chemical constitution, are more susceptible to oxidation changes than mineral oils, and consequently they are more liable to give rise to acids which corrode the metallic parts of the engine and lead to wear and tear.

Investigation[9] was undertaken by the various flying services in America to determine the relative merits of castor oil and a mineral oil (Liberty Aero Oil) as lubricants in various aeroplanes. It was found that castor oil produced a heavy shellac-like deposit and the mineral oil a light flaky one, that the engine ran more easily on mineral oil, and that castor oil absorbed gasoline, while the mineral oil did not. As a result of these experiments it was established that if castor oil was to be used, it must be changed at frequent intervals.

Peru[30], from his practical engine tests, found that considerable corrosion of the engine parts occurred even when only 20 per cent

olive oil was mixed with a mineral lubricating oil, that the oil consumption was greater than when mineral oil alone was used, and that an objectionable odour was noticeable even after a comparatively short run. Balada's[31, 32, 33, 34] extensive work on rape oil and rape-mineral oil mixtures for lubricating purposes led to similar conclusions. He found that rape seed oil when mixed with mineral oil is unstable, develops acidity, induces corrosion, increases in viscosity and emulsifies. In the motor, it increases oil consumption, clogs the filter, covers the piston rings, deposits carbon, and forms agglutinous coatings. An automobile lubricated with a mixture of 90 per cent mineral oil and 10 per cent rape oil required general repairing after a run of 10,000 kilometers. A lubricant consisting of 70 per cent mineral oil and 30 per cent rape oil did not allow a 5,000 kilometers run. A 0.5 per cent addition of a stabilizer (pyrogallol, α-naphthol, α-naphthylamine) did not improve the lubricating quality of the above oils. In the Air Ministry oxidation test of mineral oil containing 5-50 per cent of rape oil, Balada found that after 12 hr. all the mixtures were solid or sticky and gelatinous. These investigations also indicated the undesirability of mixing 5-50 per cent soya bean oil or linseed oil with a mineral lubricating oil.

It is perhaps due to rancidity that the oil, which was formerly highly valued as a lubricant for delicate machinery, is now gradually being replaced by mineral oils[35].

The literature on this subject, which has been referred to above, indicates that it is mainly the oxidation of the lubricating oil brought about by the high temperatures prevailing in internal combustion engines that causes deterioration of the oil, increases its viscosity, produces carbon, gum and sludge and forms acidic compounds which lead to the corrosion of various parts of the engine. Mineral lubricating oils are made resistant to oxidation changes, firstly, by refining so as to remove as much of the asphaltic and unsaturated materials as possible, and secondly, by adding to the refined oils certain anti-oxidants, by virtue of which the oils become stable to oxidation changes [36].

In the case of refined vegetable oils, with the exception of some work of Freund and Thamm[52], no systematic and detailed investigation appears to have been published. These investigators tested the effect of 0.5 per cent of the following oxidation inhibitors on rape oil : pyrogallol, 1 : 5-dihydroxy naphthalene; *o*-ethoxy phenol, *o*-amino phenol, dimethyl-*p*-phenylene diamine, *p*-hydroxy phenyl morpholine, benzyl aminophenol and dibenzyl aminophenol. Oxidation changes were studied by submitting the oil mixture to a laboratory oxidation test involving the passing of oxygen for five hours at the rate of 2 bubbles per second through the oil at 200°C. They found that increase in acid number was the most characteristic indication of

oxidation of the oil. The acid number increased much more in vegetable oils with inhibitors than in mineral oils. The latter, however, formed sediments during oxidation, whilst vegetable oils did not do so. Resinification was slight. Olive oil, castor oil and linseed oil were also submitted to the above oxidation tests. In practical engine tests a blend comprising a mixture of ordinary and blown rape oil without any inhibitor increased in viscosity in 25 hr. run up to 34.0°E and in acid number up to 8.06. In presence of inhibitors, these values increased after 45 hr. run to 12.2°E and 4.16 respectively. A mixture of 50 per cent mineral oil and 50 per cent rape oil in presence of inhibitors was found satisfactory.

The use of anti-oxidants for vegetable oils first originated with the classical researches of Moureau and Dufraisse [53]. A number of organic compounds to be used as anti-oxidants for rape oil and castor oil were found out by Caldwell and Dye [54], and Inman [55] respectively. But under the special conditions prevailing in internal combustion engines, the addition of an anti-oxidant is not sufficient to stabilize a lubricating oil; the compound added should also have an anti-polymerising effect.

In order to investigate systematically the possibilities of using vegetable oils as lubricants, therefore, the line of attack that first suggests itself is that which will include a study of the processes of refining and stabilizing followed by engine tests. So far as refining is concerned, the various processes now in common use may be considered as satisfactory, until as a result of further studies factors are brought to light which may demand modifications or improvements in the existing processes in order to produce satisfactory oils for use as lubricants. The work then reduces itself to investigation of methods of stabilization of oils against polymerisation and oxidation followed by practical engine trials. This Part deals with the stabilization investigations, while the engine trials are dealt with in Part II.

Experimental Procedure

With a view to ascertaining the degree of stability of oils in the laboratory without running engine tests, several methods [37] have been proposed, which are claimed to give an indication as to how an oil will behave in an engine. These methods in general include : (1) volatility tests; (2) coking tests; and (3) oxidation tests.

In the case of vegetable oils, the volatility test may be left out of consideration. For the coking test, the Conradson carbon residue method and for the oxidation test the British Air Ministry test method [38] have been generally adopted. The latter involves the passing of air at the rate of 15 litres per hr. through 40 cc. of the oil at 200°C. for two periods of 6 hr. on consecutive days. The extent of oxidation is judged by the increases in viscosity and coke number. But as this

procedure takes a long time it was concluded that oxidation could perhaps be accelerated by the use of oxygen in place of air without appreciably changing the processes of oxidation. Comparative experiments were, therefore, carried out on raw castor oil and a good quality commercial mineral lubricating oil (designated as 'A') to determine the length of time required when using oxygen, to give an equivalent degree of oxidation. The results are tabulated in Tables 2 and 3.

TABLE 2—Comparative oxidation tests on castor oil with air and oxygen

Characteristics	Original oil	Air-blown for 12 hr. (Standard test)	Oxygen-blown for			Ration of oxygen values to air values at		
			2.5 hr.	3.0 hr.	3.5 hr.	2.5 hr.	3.0 hr.	3.5 hr.
Specific gravity at 100°F./100°F.	0.9479	0.9870	0.9766	0.9809	0.9811	0.988	0.993	0.994
Viscosity at 100°F. centistokes	285.0	2096	1310.6	1851	2951.7	0.625	0.884	1.41
Acid value	4.3	4.8	5.7	6.4	6.72	1.19	1.34	1.40
Saponification value	177.3	190.7	193.2	194.4	196.4	1.01	1.02	1.03
Iodine value	97.16	78.17	78.2	76.85	75.78	1.00	0.984	0.970
Coke number	0.2	0.52	0.55	0.64	0.955	1.06	1.23	1.86

TABLE 3—Comparative oxidation tests on mineral oil 'A' with air and oxygen

Characteristics	Original oil	Air-blown for 12 hr. (Standard test)	Oxygen-blown for		Ratio of oxygen values to air values at	
			3.0 hr.	3.5 hr.	3.0 hr.	3.5 hr.
Specific gravity at 100°F./100°F.	0.8700	0.8710	0.8702	0.8706	0.999	1.00
Viscosity at 100°F. centistokes	122.8	157.3	132.0	136.7	0.838	0.868
Coke number	0.37	0.57	0.506	0.55	0.888	0.956

The last three columns in Table 2 indicate that 3 hr. oxidation with oxygen approximated much more closely to 12 hr. air-oxidation values than values obtained at either 2.5 or 3.5 hr. The correspondence was much closer as regards specific gravity, iodine value and saponification value than in the case of acid value and coke number. It will also be observed that, at 3.0 hr., although the coke number and acid value had undergone excessive change the viscosity increase had not quite come up to the value corresponding to 12 hr. with air. In the case of mineral oil, both viscosity and coke number were lower, not only at 3.0 but also at 3.5 hr., but the difference between 3.0 and 3.5 hr. figures was small. Specific gravity did not suffer much change either with air or oxygen.

On the whole, it appeared that 3 hr. oxidation with oxygen would suffice to reproduce approximately the conditions required for oxidation tests on vegetable oils, and this procedure was, therefore, adopted, i.e., keeping all the conditions of the Air Ministry oxidation test as specified, air was replaced by oxygen and the duration of oxidation reduced from 12 to 3 hr. In addition, another minor change was introduced, namely, that 50 cc. of oil sample instead of 40 cc. was used, in order to provide sufficient oil for viscosity measurement.

Subject to these variations, the results of the first set of tests on raw castor oil of low acid value, using a number of anti-oxidants, are summarised in Table 4.

TABLE 4—Effect of various stabilizers on raw castor oil when submitted to the modified oxidation test

No.	Stabilizer	Amount of stabilizer %	Viscosity at 100°F. (c.s.)	Ratio of viscosity increase	Coke number	Remarks
1	Original oil (unblown)	..	285	..	0.2	
2	Original oil (blown) ..	0.0	1852	6.5	0.64	
3	Thymol	2.0	1337	4.6	0.76	Slight black deposit
4	Orcinol	1.0	1555	5.4	0.66	
5	iso-Eugenol	1.0	2167	7.6	0.68	
6	Hydroquinone	0.25	1173	4.1	0.67	
7	do.	0.5	853	3.0	0.74	
8	do.	1.0	745	2.6	0.74	Black tarry deposit
9	β-Naphthol	1.0	970	3.4	0.73	
10	,, ...	2.0	825	2.9	0.64	
11	p-Aminophenol	0.5	912	3.2	0.7	Black deposit
12	do.	1.0	795	2.8	0.76	Hard black deposit
13	N-Phenyl β-naphthylamine	2.0	852	3.0	0.66	
14	Acetyl phenyl hydrazine	2.0	856	3.0	0.65	
15	β-Naphthylamine ..	0.5	1066	3.7	0.65	Slight black deposit
16	do.	1.0	856	3.0	0.68	Black tarry deposit
17	Diphenylamine ..	0.5	1318	4.6	0.64	
18.	do. .. .	1.0	950	3.3	0.65	
19	do.	2.0	842	2.9	..	
20	Hydroquinone and β-naphthylamine ..	0.5 each	795	2.8	..	Less black deposit
21	do.	1.0 each	600	2.1	0.78	Much black deposit
22	β-Naphthol and β-naphthylamine ..	1.0 each	744	2.6	0.65	
23	β-Naphthylamine and catechol ..	0.5 each	767	2.7	..	Black deposit
24	Tin oleate	1.0	1519	5.3	0.65	
25	Tin linoleate	1.0	1682	5.9	0.66	
26	Tin naphthenate ..	1.0	1320	4.6	0.64	
27	Chromium oleate ..	1.0	1508	5.3	0.67	
28	Chromium naphthenate ..	1.0	1169	4.1	0.64	
29	Cyclohexanol	2.0	1504	5.2	0.66	Considerable brown gummy deposit
30	Clove oil	1.0	2169	7.6	0.67	Gummy deposit

It is likely that in the presence of iron the rate of oxidation may alter. Several workers have investigated the effect of various metals on the oxidation of mineral oils. Thus Mardles and Ramsbottom [39], when determining the action of surfaces on the rate of oxygen absorption, found that tin dust exerted inhibitory action, gold had little or no effect, whilst iron and aluminium increased the rate of oxidation. Kalichevsky [40] states that the comparison of the results of oxidation tests performed in the presence and absence of certain metals often reveal considerable discrepancies, as oils stable in the absence of these metals may deteriorate relatively fast in their presence. In this connection it is of interest to note that the well-

known 'life' test for transformer oils is now practically discarded by the industry as an indication test of the stability of oils in service, and other tests using metals are now being employed in its place.

Evans & Kelman [41] remark that the reaction between oil and oxygen in a glass container must be modified if better correlation between the laboratory test and engine tests is to be obtained. It was suggested by them that this may be done by heating the oil in presence of metallic iron in a Petri dish. Whilst the increase of acidity and of solid oxidation products are of practical importance, the viscosity of the oil after oxidation appears to give close correlation with engine results; on similar grounds Barr [42] advocates the use of metal instead of glass apparatus in view of the negative effect of the latter on the oxidation of mineral oils.

With a view to studying the effect of iron in the modified Air Ministry oxidation test, preliminary experiments were carried out on raw and heated castor oils* in the presence and absence of anti-oxidants as well as on two mineral lubricating oils, one of which was the same as used in the early experiments, while the other (designated 'B') is a somewhat cheaper grade of commercial oil. To notice the effect of iron, when required, one hundred steel balls ($\frac{1}{8}$ in. diam.) were introduced into the oxidation tubes, and all the other conditions were kept constant. The results obtained are summarised in Table 5.

The results in Table 5 indicate that heat-treatment makes castor oil much more susceptible to oxidation, especially in the presence of iron, although it brings down the viscosity to the neighbourhood of that suitable for use in internal combustion engines. In the case of raw castor oil also, iron definitely promotes oxidation, but in the case of mineral oils iron appears to affect oxidation very little.

For the purpose of the present investigation, it was considered advisable, therefore, to carry out laboratory experiments in the presence of iron. The modifications, therefore, finally involved : (1) the use of oxygen in place of air; (2) an oxidation period of 3 hr. instead of 12 hr.; (3) volume of the sample, 50 cc. instead of 40 cc.; (4) the introduction in the oxidation tube of 100 clean steel balls of $\frac{1}{8}$ in. diam. The final procedure adopted was as follows :

Suitable refined vegetable oils having low acid values were treated with numerous anti-oxidants or stabilizers and their viscosities, acid values and Conradson carbon residues were determined before and after subjecting them to the modified Air Ministry oxidation test.

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* Heated castor oil was prepared by subjecting raw castor oil to a temperature of 280°-310°C. until 4.1 per cent of its weight was lost.

TABLE 5—Effect of iron on oils subjected to modified Air Ministry Oxidation Test

No.	Oil	Anti-oxidant	Without iron				With iron			
			Viscosity at 100°F. (c.s.)	Viscosity increase ratio	Acid value	Conradson carbon	Viscosity at 100°F. (c.s.)	Viscosity increase ratio	Acid value	Conradson carbon
1	Raw castor oil (unoxidised) ..	None ..	282	1.0	3.7	0.18	..	..	..	..
2	Raw castor oil	None ..	1833	6.5	4.9	1.27	2010	7.1	4.1	4.72
3	Raw castor oil	1 p.c. pyrogallol ..	882	3.13	5.6	1.6	892	3.16	5.6	1.75
4	Raw castor oil	1 p.c. benzidine ..	792	2.8	4.2	1.88	885	2.1	4.2	1.96
5	Heated castor oil (unoxidised) ..	None	133	1.0	15.4	0.17	..	..	..	..
6	Heated castor oil	None	12374	93.3	4.7	1.12	..	Resinous rubbery mass		
7	Heated castor oil	1 p.c. pyrogallol ..	1098	8.3	8.2	1.99	1354	10.2	8.0	2.25
8	Mineral oil 'A' (unoxidised) ..	None	122.6	1.0	0.0	0.19	..	..	..	..
9	Mineral oil 'A'	None	131.5	1.07	0.4	0.26	132.5	1.08	0.5	0.21
10	Mineral oil 'B' (unoxidised) ..	None	134.0	1.0	0.1	0.08	..	..	..	..
11	Mineral oil 'B'	None	218.3	1.62	1.9	1.10	210.9	1.59	1.5	1.09

Results

The results of oxidation tests under these conditions on castor, groundnut, cotton seed and rape oils when treated with various stabilizers are presented in Tables 6, 7, 8 and 9 respectively.

TABLE 6—Effect of various stabilizers on castor oil

No.	Stabilizer	Quantity of stabilizer %	Viscosity at 100°F. (c.s.)	Viscosity increase ratio blown: original	Acid value	Conradson carbon	Remarks
1	Original oil (unoxidised)	..	281.7	..	3.7	0.18	
2	Original oil (oxidised)	..	2010.0	7.1	4.1	1.72	
	Phenolic compounds						
3	Phenol	1.0	1303.6	4.6	3.8	0.93	
4	α-Naphthol ..	1.0	737.0	2.6	4.6	1.7	
5	β-Naphthol ..	2.0	865.0	3.07	5.4	1.2	
6	Nitroso α-naphthol	1.0	785.0	2.78	6.5	1.7	
7	Nitroso β-naphthol	1.0	1121.8	3.98	6.2	1.5	
8	Guaiacol	1.0	1260.0	4.47	4.6	0.87	Black deposit
9	Thymol	2.0	1337.0	4.7	..	0.67	
10	iso-Eugenol ..	1.0	2167.0	7.7	..	0.68	
11	Salicylaldehyde ..	1.0	1832.0	6.5	4.5	0.9	
12	Methyl salicylate	1.0	1327.6	4.7	3.6	0.82	
13	Di-α-naphthol azo p-phenylene ..	1.0	1067.0	3.78	4.3	0.97	
14	Di-α-naphthol azo p-diphenyl ..	1.0	1056.0	3.74	4.2	1.2	
15	α-Naphthol azo α-naphthalene	1.0	734.0	2.6	5.4	0.94	
16	Hydroquinone ..	1.0	762.4	2.7	5.9	1.2	
17	Orcinol	1.0	1555.0	5.5	..	0.66	
18	o:o'-Dioxy diphenyl	1.0	1178.0	4.18	5.5	1.35	
19	Pyrogallol ..	1.0	892.0	3.16	5.6	1.75	
20	Phloroglucinol ..	1.0	666.6	2.36	5.6	1.18	
21	Gallic acid ..	1.0	900.5	3.2	5.8	1.28	
22	Methyl gallate ..	1.0	949.8	3.38	5.4	1.15	
23	Gallic anilide ..	1.0	958.0	3.4	5.4	1.28	
24	Cresylic acid ..	1.0	1705.0	6.0	4.6	0.67	
25	Creosote from beach tar	1.0	1273.0	4.5	4.4	0.62	
	Amino compounds						
26	Aniline	1.0	1116.2	3.9	4.0	1.04	
27	α-Naphthylamine ..	1.0	767.0	2.7	5.0	1.41	
28	β-Naphthylamine ..	1.0	737.0	2.6	5.7	1.40	
29	N-Phenyl α-naphthylamine	1.0	796.0	2.8	5.5	0.85	
30	p-Toluidine ..	1.0	755.4	2.67	4.3	1.0	
31	p-Anisidine ..	1.0	821.6	2.9	5.4	1.08	
32	p-Amino acetanilide	1.0	895.0	3.1	5.0	1.45	
33	p-Aminoazobenzene	1.0	940.6	3.33	5.8	2.0	
34	Triethanolamine ..	1.0	1135.9	4.03	6.0	1.3	Slight black deposit
35	Urethane ..	1.0	1252.9	4.4	4.3	0.68	
36	Glycine	1.0	1198.0	4.2	4.1	1.05	Partially soluble
37	Glutamic acid ..	1.0	1179.6	4.18	4.3	0.69	do.
38	Pyridine	1.0	1402.0	4.97	4.2	0.74	

TABLE 6—(Continued)

No.	Stabilizer	Quantity of stabilizer %	Viscosity at 100°F. (c.s.)	Viscosity increase ratio blown: original	Acid value	Conradson carbon	Remarks
39	Piperidine ..	1.0	989.3	3.5	4.1	0.8	
40	Dibenzyl p-aminophenol	1.0	958.0	3.4	4.8	1.0	
41	1-Amino-4-naphthol hydrochloride	0.5	1127.4	4.0	5.5	1.6	Partially soluble, brown gummy deposit
42	Benzidine ..	1.0	885.0	3.1	4.2	1.96	
43	o-Toluidine ..	1.0	928.0	3.3	4.3	1.69	
44	p-Phenylene diamine	1.0	824.0	2.9	4.3	1.5	
45	Phenyl hydrazine ..	1.0	989.3	3.5	4.5	1.16	
46	assym. Diphenyl hydrazine ..	1.0	786.4	2.78	5.6	1.2	
47	Diphenylamine ..	1.0	845.0	3.0	5.8	1.02	
48	p:p′-Diamino diphenylamine sulphate	1.0	930.0	3.3	5.6	0.95	Black deposit
49	p:p′-Diamino diphenylamine	1.0	699.0	2.48	5.9	0.82	Partially soluble
50	do.	0.5	868.0	3.08	6.0	0.9	do.
51	Urea	1.0	1344.0	4.77	3.8	0.6	
52	n:n′-Diphenylurea ..	1.0	1133.0	4.04	4.1	1.1	Partially soluble
53	Uric acid	1.0	1624.9	5.76	4.0	1.1	Sparingly soluble
54	Alloxan	1.0	1139.0	4.04	4.3	0.84	Partially soluble
55	Diphenyl guanidine	1.0	1106.3	3.92	5.0	1.14	
56	Hexamine ..	1.0	935.8	3.3	5.6	0.69	Partially soluble, brown gummy deposit
	Organo-metallic compounds						
57	Tin oleate ..	0.1	1214.0	4.3	3.9	0.7	Sparingly soluble
58	Tin linoleate ..	0.1	1247.0	4.4	3.9	1.0	
59	Chromium oleate ..	0.1	1214.8	4.3	3.8	0.77	..
60	Nickel oleate ..	0.1	1217.6	4.3	3.7	0.87	Partially soluble
61	Lead oleate ..	0.1	1274.0	4.5	3.9	1.06	Very sparingly soluble
62	Lead tetraethyl ..	1.0	1296.5	4.6	4.4	2.2	
	Sulphur compounds						
63	p-Toluoyl sulphonyl chloride	1.0	3819.0	13.5	8.2	1.5	Much black deposit
64	Diamyl disulphide ..	1.0	1268.0	4.5	3.6	1.4	Brownish black deposit
65	Allyl isothiocyanate	1.0	1152.8	4.1	5.3	1.5	Black tarry deposit
	Miscellaneous substances						
66	Oildag	2.0	1514	5.3	3.6	1.0	
67	Furfural	1.0	1469	5.2	3.96	1.3	
68	Camphor ..	1.0	1589.7	5.64	5.1	0.68	
	Mixtures of various substances						
69	Hydroquinone and β-naphthylamine	0.5 each	718.7	2.55	5.1	0.95	
70	Hydroquinone and α-naphthol	0.5 each	734.9	2.6	5.1	1.8	
71	β-Naphthylamine and α-naphthol	0.5 each	775.1	2.75	5.6	1.1	
72	Tin oleate and .. α-naphthol	0.1 and 1.0	737.0	2.6	4.9	1.5	
73	Tin linoleate and .. α-naphthol	0.1 and 1.0	735.7	2.6	4.3	1.9	
74	Chromium oleate and α-naphthol	0.1 and 1.0	737.0	2.6	4.4	1.6	

TABLE 6—(Continued)

No.	Stabilizer	Quantity of stabilizer %	Viscosity at 100°F. (c.s.)	Viscosity increase ratio blown: original	Acid value	Conradson carbon	Remarks
75	Nickel oleate and α-naphthol	0.1 and 1.0	745.0	2.6	4.5	1.42	
76	Lead oleate and α-naphthol	0.1 and 1.0	739.8	2.6	4.0	1.57	
77	Aluminium stearate and α-naphthol	0.1 and 1.0	792.0	2.8	4.6	1.4	Partially soluble
78	Iron oleate and α-naphthol	2.0 and 1.0	948.0	3.36	5.3	1.5	Partially soluble and reddish brown deposit
79	α-naphthol and oildag	1.0 and 2.0	731.0	2.6	4.0	1.55	
80	α-Naphthylamine and oildag	1.0 and 2.0	764.0	2.7	4.8	1.34	

TABLE 7—Effect of various stabilizers on groundnut oil

No.	Stabilizer	Quantity of stabilizer %	Viscosity at 100°F. (c.s.)	Viscosity increase ratio blown: original	Acid value	Conradson carbon	Remarks
1	Original oil (unoxidised)	..	41.1	..	1.5	0.3	
2	Original oil (oxidised)	..	377.5	9.2	2.7	0.85	
	Phenolic compounds						
3	α-Naphthol ..	1.0	198.0	4.8	3.8	1.6	
4	α-Naphthol ..	2.0	175.0	4.2	3.6	2.3	
5	β-Naphthol ..	0.5	347.3	8.4	3.2	1.03	
6	β-Naphthol ..	1.0	302.8	7.3	3.2	1.2	
7	Thymol	1.0	347.6	8.4	2.7	0.87	
8	Eugenol	1.0	339.0	8.2	3.0	1.1	
9	isoEugenol ..	1.0	295.8	7.2	2.6	0.91	
10	Salicyl aldehyde ..	1.0	360.4	8.7	2.3	0.70	
11	Catechol	1.0	292.5	7.1	3.1	1.8	
12	Resorcinol ..	1.0	273.1	6.6	2.9	1.1	Black deposit
13	Hydroquinone ..	1.0	220.5	5.3	4.0	1.4	Sparingly soluble
14	Orcinol	1.0	262.3	6.4	3.4	1.37	Slight brownish black deposit
15	Pyrogallol ..	1.0	273.8	6.6	3.5	1.8	Slight black deposit
16	Phloroglucinol ..	1.0	203.4	4.9	3.5	1.4	Sparingly soluble
17	Methyl gallate ..	0.1	377.5	9.2	2.9	0.9	
18	α-Naphthol azo α-naphthalene ..	1.0	248.0	6.03	3.3	1.7	Sparingly soluble
	Amino compounds						
19	α-Naphthylamine ..	1.0	227.0	5.5	3.7	1.21	
20	β-Naphthylamine ..	1.0	233.6	5.7	3.06	1.5	
21	n-Phenyl-α-naphthylamine	1.0	212.4	5.1	3.3	1.28	
22	p-Toluidine ..	1.0	236.4	5.7	4.0	0.99	
23	p-Amino acetanilide	1.0	330.8	8.0	2.8	0.76	
24	p-Aminophenol ..	0.5	378.4	9.2	2.7	0.76	Partially soluble
25	Diphenylamine ..	1.0	300.0	7.3	3.06	0.76	Slight black deposit
26	N-Acetyl diphenylamine	1.0	347.9	8.4	2.3	0.81	
27	p:p'-Diamino diphenylamine ..	0.5	294.0	7.1	4.4	1.09	Partially soluble
28	Glycine	1.0	295.3	7.1	3.6	1.3	Partially soluble slight deposit
29	Diethylaniline ..	2.0	279.4	6.7	2.6	0.9	Partially soluble

TABLE 7—(Continued)

No.	Stabilizer	Quantity of stabilizer %	Viscosity at 100°F. (c.s.)	Viscosity increase ratio blown : original	Acid value	Conradson carbon	Remarks
30	m-phenylenediamine	1.0	300.3	7.3	2.7	1.3	Partially soluble slight black deposit
31	p-phenylenediamine	0.5	287.2	7.0	2.7	1.56	Slight black deposit
32	p-phenylenediamine	1.0	282.5	6.8	2.9	1.6	Partially soluble, black hard deposit
33	Benzidine ..	0.5	313.0	7.6	2.8	1.39	
34	o-Toluidine ..	0.5	376.9	9.1	3.0	1.39	
35	Phenyl hydrazine ..	1.0	257.8	6.2	2.4	1.1	
36	Acetyl phenyl hydrazine	1.0	258.2	6.2	2.8	1.1	Partially soluble, slight black deposit
37	Assym. Diphenyl hydrazine ..	1.0	233.0	5.6	3.3	1.1	
	Organo-metallic compounds						
38	Chromium naphthenate	1.0	439.8	10.7	2.7	1.02	Slight gummy deposit
39	Chromium oleate ..	1.0	520.8	12.6	2.7	1.28	Slight gummy deposit
40	Tin linoleate ..	1.0	502.8	12.2	4.6	1.32	
41	Tin naphthenate ..	1.0	452.6	11.0	3.4	2.7	
42	Tin oleate ..	1.0	394.0	9.6	3.4	1.6	Partially soluble
43	Chromium oleate ..	0.1	363.2	8.8	3.5	0.7	
44	Tin linoleate ..	0.1	380.6	9.2	3.4	0.8	
45	Tin oleate ..	0.1	384.4	9.3	3.48	1.0	
	Miscellaneous substances						
46	Oildag	2.0	354.0	8.6	4.8	1.12	
47	Indigo	1.0	273.2	6.6	2.5	0.92	Partially soluble
48	Citric acid ..	1.0	506.2	12.3	2.2	0.7	
49	Tartaric acid ..	1.0	374.4	9.1	2.9	1.08	
50	Phthalic anhydride	1.0	430.0	10.0	3.4	0.92	
51	Benzophenone ..	1.0	393.0	9.5	2.7	0.83	
52	Furfural	1.0	320.0	7.7	2.2	0.71	
53	Vanillin	1.0	360.0	8.7	3.3	0.82	
	Mixtures of various substances						
54	Hydroquinone and β-naphthylamine ..	0.5 each	205.0	5.0	3.6	1.1	Slight black deposit
55	do. ..	1.0 each	166.2	4.0	4.3	2.1	Black deposit
56	Hydroquinone and α-naphthol ..	0.5 each	190.6	4.6	4.0	0.72	Slight black deposit
57	β-Naphthylamine and α-naphthol ..	0.5 each	211.2	5.1	3.9	1.4	
58	Chromium oleate and α-naphthol ..	0.1 and 1.0	200.3	4.8	4.8	1.7	
59	Tin linoleate and α-naphthol ..	0.1 and 1.0	209.3	5.0	4.1	1.75	
60	Oildag and α-naphthol ..	2.0 and 1.0	197.8	4.8	5.1	1.77	

TABLE 8—Effect of various stabilizers on cottonseed oil

No.	Stabilizer	Quantity of stabilizer %	Viscosity at 100°F. (c.s.)	Viscosity increase ratio blown: original	Acid value	Conradson carbon	Remarks
1	Original oil (unoxidised)	..	37.38	..	0.15	0.23	
2	Original oil (unoxidised)	..	450.6	12	1.8	1.07	
	Phenolic compounds						
3	α-Naphthol	1.0	244.2	6.5	2.03	1.6	
4	β-Naphthol	1.0	276.6	7.3	1.6	1.05	
5	Nitroso α-naphthol	1.0	288.4	7.7	2.4	1.16	
6	Nitroso β-naphthol	1.0	381.6	10.6	2.1	1.08	
7	Guaiacol	1.0	409.9	11.0	1.7	1.06	
8	Thymol	1.0	445.4	11.8	1.6	1.24	
9	Catechol	1.0	378.8	10.1	1.9	1.4	
10	Resorcinol	1.0	317.7	8.4	2.1	1.38	
11	Hydroquinone	1.0	280.3	7.5	2.1	1.4	
12	Orcinol	1.0	337.0	9.0	1.9	1.4	Slight gummy deposit
13	Pyrogallol	1.0	324.6	8.6	1.8	1.7	
14	Gallic acid	1.0	334.9	8.9	2.7	1.26	Sparingly soluble
15	Methyl gallate	1.0	420.6	11.2	2.2	0.95	
16	Gallic anilide	1.0	301.1	8.0	2.9	1.4	
	Amino compounds						
17	α-Naphthylamine	1.0	242.0	6.47	2.1	1.34	
18	β-Naphthylamine	1.0	270.4	7.2	1.9	1.33	
19	N-Phenyl α-naphthylamine	1.0	305.3	8.1	2.8	1.7	
20	p-Anisidine	1.0	350.8	9.3	2.3	1.7	Very slight brown deposit
21	p-Aminophenol	1.0	470.4	12.5	2.4	2.1	Partially soluble
22	Diphenylamine	1.0	337.0	9.0	2.0	1.28	
23	N-Acetyl diphenylamine	1.0	404.0	10.8	1.3	0.93	
24	4:4′-Diamino diphenylamine sulphate	1.0	472.8	12.6	2.5	0.72	Insoluble, black tarry deposit
25	p-Aminoazo-benzene	1.0	391.8	10.4	1.3	1.13	Slight brownish gummy deposit
26	p-Amino acetanilide	1.0	404.6	10.8	1.92	0.98	
27	Pyridine	1.0	467.8	12.5	1.6	0.92	
28	Piperidine	1.0	340.8	9.1	1.9	1.1	Black deposit
29	Tri-ethanolamine	1.0	514.0	13.7	1.7	0.87	
30	p-Phenylenediamine	1.0	433.9	11.6	2.4	1.43	Partially soluble, lot of black deposit
31	Benzidine	1.0	449.1	12.0	2.2	2.1	Partially soluble, brown deposit
32	o-Toluidine	1.0	450.1	12.0	1.9	1.7	
33	Phenylhydrazine	1.0	407.4	10.9	1.3	0.8	
34	Acetyl phenylhydrazine	1.0	281.9	7.5	1.8	1.3	Partially soluble, brownish black deposit
35	Diphenyl guanidine	1.0	456.0	12.2	1.9	1.2	Slight black deposit
36	Urethane	1.0	537.3	14.2	1.6	0.8	do.
37	Hexamine	1.0	486.8	13.0	1.5	1.16	Sparingly soluble, much black deposit
	Sulphur compounds						
38	Allyl isothiocyanate	1.0	420.2	11.2	2.4	1.28	Black deposit
	Mixture of phenol and amine						
39	α-Naphthol and α-naphthylamine	0.5 each	267.6	7.16	2.3	1.79	

TABLE 9—Effect of various stabilizers on rape oil

No.	Stabilizer	Quantity of stabilizer %	Viscosity at 100°F. (c.s.)	Viscosity increase ratio blown: original	Acid value	Conradson carbon	Remarks
1	Original oil (unoxidised)	..	46.9	..	0.52	0.28	
2	Original oil (oxidised)	..	350.6	7.47	4.1	1.25	
	Phenolic compounds						
3	α-naphthol ..	1.0	170.4	3.6	4.6	1.7	
4	β-naphthol ..	1.0	173.2	3.7	4.9	1.25	
5	Nitroso α-naphthol	1.0	170.4	3.6	3.6	2.8	
6	Nitroso β-naphthol ..	1.0	215.5	4.6	3.6	2.5	
7	Eugenol	1.0	224.9	4.8	4.5	1.5	
8	iso-Eugenol ..	1.0	206.5	4.4	5.2	1.95	
9	Guaiacol	1.0	232.0	4.9	4.6	2.1	
10	Thymol	1.0	237.7	5.0	5.1	1.8	
11	Methyl salicylate ..	1.0	245.0	5.2	4.6	1.66	
12	Salicylaldehyde ..	1.0	226.0	4.6	3.6	1.26	
13	α-Naphthol azo α-naphthalene ..	1.0	210.7	4.5	4.3	1.83	Partially soluble
14	Di-α-naphthol azo p-diphenyl ..	1.0	297.6	6.34	3.4	2.23	do.
15	Di-α-naphthol azo p-phenylene ..	1.0	250.5	5.3	2.89	1.56	do.
16	Catechol	1.0	190.0	4.05	4.8	1.75	
17	Resorcinol ..	1.0	168.6	3.58	4.9	1.7	Sparingly soluble
18	Hydroquinone ..	1.0	170.2	3.6	4.9	1.7	
19	Orcinol	1.0	183.7	3.9	4.2	2.08	
20	o:o'-Dioxy diphenyl	1.0	205.8	4.37	5.05	1.75	
21	Pyrogallol ..	1.0	219.3	4.66	4.7	1.9	Sparingly soluble
22	Phloroglucinol ..	1.0	165.0	3.5	4.2	2.0	do.
23	Gallic acid ..	1.0	234.7	5.0	3.77	1.6	Very sparingly soluble
24	Methyl gallate ..	1.0	224.8	4.8	4.0	1.63	Sparingly soluble
25	Gallic anilide ..	1.0	230.1	4.9	3.77	1.56	Sparingly soluble
	Amino compounds						
26	α-Naphthylamine ..	1.0	169.4	3.6	4.2	2.3	
27	β-Naphthylamine ..	1.0	173.2	3.69	4.05	2.3	
28	N-Phenyl α-naphthyl-amine	1.0	165.0	3.5	4.5	1.9	Slightly soluble
29	p-Toluidine ..	1.0	191.5	4.08	4.1	2.2	
30	p-Anisidine ..	1.0	196.2	4.18	4.3	1.0	
31	p-Aminophenol ..	1.0	206.2	4.4	5.0	1.45	Sparingly soluble
32	Dibenzyl-p-amino-phenol	1.0	365.5	7.8	2.1	2.0	do.
33	Glycine	1.0	185.0	4.0	4.8	1.43	Partially soluble
34	Glutamic acid ..	1.0	302.5	6.4	4.8	1.45	do.
35	Anthranilic acid ..	1.0	277.0	5.9	4.8	1.37	
36	p-Aminoazobenzene	1.0	224.9	4.8	3.25	1.9	
37	p-Amino acetanilide	1.0	310.8	6.6	3.0	1.5	Slightly soluble
38	Quinoline ..	1.0	294.9	6.3	3.9	1.66	
39	Pyridine ..	1.0	353.6	7.5	3.26	1.97	
40	Piperidine ..	1.0	300.6	6.4	4.1	1.9	
41	Tri-ethanolamine ..	1.0	362.5	7.7	3.33	1.28	
42	Urethane	1.0	286.0	6.1	4.26	2.05	

TABLE 9—(Continued)

No.	Stabilizer	Quantity of stabilizer %	Viscosity at 100°F. (c.s.)	Viscosity increase ratio blown: original	Acid value	Con-radson carbon	Remarks
43	Diphenylamine ..	1.0	147.2	3.13	3.75	1.28	
44	N-Acetyl diphenyl amine ..	1.0	312.3	6.6	3.1	1.5	
45	4:4'-Diamino diphenyl amine	0.5	217.0	4.6	4.2	2.9	Partially soluble
46	p-Phenylene-diamine	1.0	232.8	4.96	3.0	1.87	do.
47	Benzidine ..	1.0	215.4	4.58	3.75	2.75	Sparingly soluble
48	o-Toluidine ..	1.0	200.7	4.27	4.2	2.7	Very sparingly soluble
49	Phenylhydrazine ..	1.0	256.0	5.45	3.7	1.9	
50	Acetyl phenylhydrazine	1.0	232.0	4.94	3.05	1.43	
51	Assym. Diphenyl-hydrazine ..	0.5	211.8	4.5	4.9	1.7	
52	do. ..	1.0	130.9	2.8	5.0	1.85	
53	Diphenyl urea ..	1.0	271.0	5.77	3.6	1.05	Sparingly soluble
54	Alloxan	1.0	313.8	6.7	4.03	1.54	Mostly insoluble
55	Diphenyl guanidine	1.0	267.9	5.7	4.0	1.7	do.
56	Uric acid	1.0	412.5	8.7	4.45	1.63	Very sparingly soluble
57	Hexamine ..	1.0	350.6	7.4	3.47	1.7	
58	Tetra methyl diamino diphenyl methane	1.0	203.3	4.3	4.43	1.51	
59	1-Amino 4-naphthol hydrochloride	0.5	424.3	9.0	2.3	2.66	Partially soluble
60	Semicarbazide hydrochloride ..	1.0	531.9	11.3	2.48	2.46	Sparingly soluble
	Organo-metallic compounds						
61	Chromium oleate ..	1.0	645.3	13.7	3.85	2.6	Not entirely soluble
62	Tin linoleate ..	1.0	455.3	9.6	4.7	2.18	
	Sulphur compounds						
63	Diamyl disulphide ..	1.0	300.6	6.4	4.1	2.3	
64	Allyl isothiocyanate	1.0	321.2	6.8	3.4	2.3	
	Miscellaneous substances						
65	Oildag	2.0	371.3	7.9	3.25	2.23	
66	Benzophenone ..	1.0	280.0	6.0	3.86	2.09	
67	Vanillin ..	1.0	259.3	5.5	4.7	2.16	
68	Furfural	1.0	275.6	5.87	4.8	1.34	
69	Camphor	1.0	256.0	5.45	3.5	1.43	
	Mixture of amine and phenol						
70	α-Naphthylamine and α-naphthol	0.5 each	176.2	3.7	3.85	2.6	Not entirely soluble

It may be mentioned that in the case of rape oil, some black gummy deposits were almost always found in the oxidation tubes (cf. Table 9). The fact that such black deposits were also obtained in the case of castor, groundnut and cottonseed oils when they were subjected to the oxidation tests in the presence of stabilizers containing sulphur led to the belief that the rape oil deposits might be due to the presence of allyl *iso*thiocyanate. So to remove allyl *iso*thiocyanate from rape oil, the following methods were adopted :

(a) Rape oil was extracted several times with alcohol and the residue heated at 100°C. to remove any dissolved alcohol.

(b) Rape oil was distilled in steam till no more oily globules were removed. The remaining oil was separated from water and dried at 100-110°C.

Both the oil samples so obtained, when subjected to the oxidation test, gave similar black deposits in the oxidation tubes. These oils exhibited rather a greater tendency to oxidation than the original oil, as may be seen from the results given in Table 10.

The effect appears to be due to the removal of naturally occurring anti-oxidants, such as have been observed by other investigators[60].

TABLE 10—Effect of various treatments on oxidation behaviour of refined rape oil

No.	Oil	Viscosity at 100°F. (c.s.)	Viscosity increase ratio	Acid value	Conradson carbon
1	Original oil (unblown) ..	46.9	..	0.52	0.28
2	Original oil (blown) ..	350.6	7.47	4.1	1.25
3	Alcohol extracted oil (blown)	367.3	7.83	2.7	1.3
4	Steam distilled oil (blown)	496.8	10.6	3.47	1.85

Discussion

It is clear from Tables 6, 7, 8 and 9 that a large proportion of the substances tried fail to serve as efficient stabilizers. Nevertheless, there are some which may be regarded as satisfactory. The data concerning such materials have been collected in Table 11 for all the four oils.

A comparison of the results obtained for vegetable oils with those of the two mineral lubricating oils dealt with in Table 5 shows that the vegetable oils, especially in the presence of iron, polymerize much more readily than the mineral oils, and even in the presence of stabilizers they become more acidic and give higher Conradson carbon residues than the mineral oils. It may be pointed out incidentally that, contrary to the conclusions of Balada[33], the Conradson carbon test appears to be applicable under these conditions to vegetable oils. Thus, although vegetable oils as such give little Conradson carbon residue, yet after the oxidation test they generally showed more residue than mineral oils treated similarly.

The large increase in polymerization and oxidation of the vegetable oils as compared with the mineral oils may be due to two reasons :

(1) Difference due to chemical constitution : Vegetable oils, being esters by nature, are more prone to undergo various chemical changes, such as oxidation, hydrolysis, condensation, etc. than mineral oils, which are mainly mixtures of paraffins and naphthenic and aromatic hydrocarbons.

(2) Unsaturation : Mineral oils are less unsaturated than vegetable oils. This is undoubtedly one of the reasons why the former undergo less change after the oxidation test than the latter.

Comparing the unsaturation of the two mineral oils, whose characteristics are given in Table 5, it will be noted that oil 'B' has a higher iodine value (25.6) than oil 'A' (11.3), in fact the former polymerized to a greater extent than the latter. As regards the unsaturation of the four vegetable oils that were exhaustively subjected to oxidation tests, cottonseed oil possesses the greatest iodine value (103-115), while castor oil shows the least (82-90). Here again irrespective of the fatty acid contents of the four oils, the oxidation test results show that the polymerization of cottonseed oil was the greatest, even in the presence of stabilizers, while in the case of castor oil it was the least.

Of all the stabilizers found effective for castor oil, an appreciable number proved satisfactory for rape and groundnut oils, while very few of these were effective in the case of cottonseed oil. Stated in another way, the largest number of substances proved to be effective in the case of castor oil and the least number for cottonseed oil. These results are corroborated by Lewkowitsch[43]. Unfortunately low iodine value vegetable oils, such as coconut oil and various vegetable tallows, are solid at ordinary temperatures and in order to make use of them as lubricants methods would need to be found to keep them liquid at sufficiently low temperatures.

The above observations lead to the conclusion that, besides unsaturation, the effectiveness of various stabilizers towards vegetable oils depends on the nature of fatty acids, the constitution of the glycerides and the unsaponifiable matter present in them. For, whereas the difference between the iodine values of rape oil (94-105) and cottonseed oil (103-115) is very small, the former can be stabilized much better by a greater number of stabilizers than the latter. Similarly, castor oil lends itself to far better stabilization than groundnut oil, although both of them have nearly identical iodine values (82-90 and 83-95 respectively). Moreover, although the iodine value of rape oil (94-105) is slightly higher than that of groundnut

oil (83-95), the former can be stabilized more effectively than the latter.

Although castor oil has proved to be the most satisfactory oil so far tried, Parish[9] and several other investigators have found that castor oil, when used as a lubricant in aeroplane engines, produces a heavy shellac-like deposit. This was probably due to the absence of an effective stabilizer. As pointed out by Bauman and Zamyshlyaeva[44], the deposit may be due to the decomposition of ricinoleic acid to $Me(CH_2)_5CH:CH:CH:CH:(CH_2)_7COOR$, which is very easily polymerised.

Taking into consideration the various stabilizers that have been tried so far on the four vegetable oils, it will be seen that the choice of types of compounds to be used as stabilizers is very much more restricted in the case of vegetable oils than in the case of mineral oils. Tin compounds[45] and other organo-metallic compounds[36] that have been proved to possess pronounced anti-oxidant properties in the case of mineral oils are of little value in the case of vegetable oils. Chromium and tin compounds (which have been subjects of patents—the former by Griffith and Helmore[46] and the latter by Helmore and Mardles[47]—as anti-oxidants for mineral oils), have proved to be pro-oxidants with refined groundnut oil (Table 7, compare items 2 and 38-42) and rape oil (Table 9, compare items 2 and 61-62). Similarly colloidal graphite, found to act as a good anti-oxidant for mineral lubricants by Weiss and Maillard[29], is much less effective in the case of vegetable oils.

The organic sulphur compounds on which many patents[48, 49, 50] have been taken out, based on claims as to their beneficial effect in mineral lubricating oils required to operate under high pressures, high temperatures, high speed conditions, and as protecting agents against oxidation, have been found to be of very little value as stabilizers in the case of vegetable oils. They generally resulted in a quantity of black tarry deposit in the oxidation tubes.

Generally speaking, the stabilizers which have proved to be the most effective are the phenols and the aromatic amino compounds, but it appears that neither the phenolic hydroxyl groups nor the amino groups are by themselves responsible for the anti-oxidant properties. Had such been the case, compounds having three phenolic hydroxyl groups, such as pyrogallol, and those having two amino groups, such as *p*-phenylene-diamine, would have proved to be the best stabilizers.

It can, however, be stated that the effect appears to be, to some extent, due to the inherent constitution of the compounds having such groups. It also appears to depend upon the position of the groups in the molecule, as will be seen from the [illegible] that α-naphthol proved to be one of the best stabilizers so far ti[illegible] for all the four

oils, while β-naphthol showed only a feeble stabilizing effect except in the case of rape oil. Similarly, hydroquinone and phloroglucinol proved quite good stabilizers, whereas catechol, resorcinol, and pyrogallol were generally not so effective. Another conclusion that may be drawn from the list of the most effective stabilizers (Table 11) is that most of them are compounds containing more than one benzene nucleus.

Comparing the increase in acid value and in Conradson carbon residue, it will be seen that they bear no relationship to the viscosity ratio figures. Substances resulting in the least increase in the acid value and carbon residue may give high viscosity increase ratios. It appears, therefore, that the best plan would be to use such mixtures of stabilizers as would help to stabilize viscosity as well as other characteristics.

Several theories have been proposed to explain the mechanism of the action of anti-oxidants on fats and oils. Lea[60] gives a brief discussion of some of these theories. Moureau and Dufraisse[53] presume that the peroxides of oils formed as a result of the action of oxygen may be reduced by the anti-oxidant directly or alternatively, oil peroxides and anti-oxidant peroxides react to reduce each other in a somewhat analogous manner to that of ozone and hydrogen

TABLE 11—Summary of oxidation test results with efficient

No.	Stabilizer	Quantity of stabilizer %	Castor oil		
			Viscosity increase ratio	Acid value increase	Conradson carbon increase
1	None	..	7.1	0.4	1.54
2	α-Naphthol	1.0	2.6	0.9	1.52
3	α-Naphthylamine	1.0	2.7	1.3	1.23
4	Phloroglucinol	1.0	2.36	1.9	1.0
5	β-Naphthylamine	1.0	2.6	2.0	1.22
6	Hydroquinone	1.0	2.7	2.2	1.02
7	assym. Diphenyl hydrazine	1.0	2.78	1.9	1.02
8	N-Phenyl α-naphthylamine	1.0	2.8	1.8	0.67
9	Nitroso α-naphthol	1.0	2.8	2.8	1.52
10	Diphenylamine	1.0	3.0	2.1	0.84
11	p-Toluidine	1.0	2.67	0.6	0.82
12	p:p'-Diamino diphenyl amine	1.0	2.48	2.3	0.64
13	α-Naphthol azo α-naphthalene	1.0	2.6	1.7	0.76
14	p-Anisidine	1.0	2.9	1.7	0.90
15	p-Phenylene-diamine	1.0	2.9	0.6	1.32
16	β-Naphthol	1.0	..	..	..
17	Resorcinol	1.0	..	..	..
18	No. 5 and 6	0.5 each	2.55	1.4	0.77
19	No. 2 and 6	0.5 each	2.6	1.4	1.62
20	No. 2 and 5	0.5 each	2.75	1.9	0.92
21	No. 2 and 3	0.5 each	..	..	..

83-

peroxide. In other words the various reactions postulated may be expressed as follows :

$$F + O_2 \rightarrow FO_2$$
$$FO_2 + A \rightarrow F + AO_2$$
$$FO_2 + A \rightarrow FO + AO \rightarrow F + A + O_2$$
$$FO_2 + AO_2 \quad F + A + 2O_2$$

where F represents oil and A the anti-oxidant.

The reactions presume that the anti-oxidant is regenerated again and again, but experimental evidence exists[58, 59] to the contrary, which shows that the anti-oxidant actually gets consumed and that it chiefly functions as an enhancer of the induction period. Thus the chain theory of Christiansen[57] carries considerable weight; chain reactions of the following type are postulated :

$$F + \text{energy} \rightarrow F^*$$
$$F^* + O_2 \rightarrow F^*O_2$$
$$F^*O_2 + F \rightarrow FO_2 + F^*$$
$$F^* + O_2 \rightarrow \ldots\ldots\ldots\ldots\ldots\text{etc.}$$

where * indicates activated molecule.

In ordinary cases such chains may be thousands of molecules long. But with the introduction of a small quantity of anti-oxidant the chain may be abruptly terminated thus :

$$F^*O_2 + A \rightarrow FO_2 + A^*$$
$$A^* + O_2 \rightarrow AO_2 \text{ stop.}$$

stabilizers for castor, rape, groundnut and cottonseed oils

Rape oil			Groundnut oil			Cotton seed oil		
Viscosity increase ratio	Acid value increase	Conradson carbon increase	Viscosity increase ratio	Acid value increase	Conradson carbon increase	Viscosity increase ratio	Acid value increase	Conradson carbon increase
7.47	3.58	0.97	9.2	1.2	0.55	12.0	1.65	0.84
3.6	4.08	1.42	4.8	2.3	1.3	6.5	1.88	1.37
3.6	3.68	2.02	5.5	2.2	0.91	6.47	1.95	1.11
3.5	3.68	1.62	4.9	2.0	1.1	..	..	..
3.69	3.53	2.02	5.7	1.56	1.2	..	..	..
3.6	4.38	1.42	5.3	2.5	1.1	..	..	..
2.8	4.48	1.57	5.6	1.8	0.8	..	..	..
3.5	3.98	1.62	5.1	1.8	0.98	..	..	..
3.6	3.08	2.52	..	..	..	..	..	..
3.13	3.23	1.00	..	..	..	..	..	..
..	..	..	5.7	2.5	0.69	..	..	..
..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..
3.7	4.38	0.97	..	..	..	..	..	..
3.58	4.38	1.42	..	..	..	..	..	..
..	..	..	5.0	2.1	0.8	..	..	..
..	..	..	4.6	2.5	0.42	..	..	..
..	..	..	5.1	2.4	1.1	..	..	..
3.7	4.45	2.02	..	..	..	..	..	..

Dhar[56] has put forward similar ideas to explain the phenomenon in terms of negative catalysis with the further modification that molecules activated by the anti-oxidant may combine with activated molecules of the oil to form additive or adsorptive compounds.

All these theories have been confined to the discussion of anti-oxidants, whereas the present work is chiefly concerned with substances which may more adequately be termed stabilizers in as much as they are expected to serve a two-fold function—that of an anti-oxidant and that of an anti-polymerizing agent. It is clear, however, that, so far as these theories are concerned, they will apply equally well to the consideration of the anti-polymerization effect, if the oxygen molecule was replaced by another molecule of the oil. Furthermore, polymerization may also be thought to take place through the oxidised positions of the oil molecule, in which case, strictly speaking, the reaction should be considered as a condensation reaction. The two-fold function of the stabilizer would naturally limit the choice of the number of substances which may be capable of performing efficiently both functions.

It will be noted that most of the stabilizers found to be effective in these investigations are such as may be easily oxidised. This is in accordance with the chain theory of Christiansen and the anti-catalyst theory of Dhar. Further weight is lent to these theories from the results obtained in actual engine trials, which show that the main effect of stabilizers is to increase the induction period.

In addition to the desirability of stabilizing the lubricant, it is important that, in an engine under running conditions, the lubricant should not attack the various engine parts, thus phenols being acidic in character may attack the metal of the engine. It may be possible in some cases, however, to inhibit the corrosive properties of a stabilizer without impairing its effectiveness.

Another consideration that requires to be taken into account when selecting a stabilizer is its tendency to lead to gum formation and ring sticking. The substances grouped in Table 11 are those which showed no such tendency in the laboratory tests, but engine tests would finally decide whether or not they are really effective from this point of view under actual working conditions.

SUMMARY

With a view to devising vegetable oil blends suitable for use as lubricants for internal combustion engines, a large number of substances has been examined as regards their stabilizing effect on castor, groundnut, cottonseed and rape oils. The laboratory procedure developed in the course of the investigations is based on the oxidation technique of the Air Ministry modified to accelerate the rate of oxidation. Changes in viscosity, acid value and Conradson carbon residue were determined before, and after oxidation.

A number of substances were found to be effective stabilizers for castor oil. Stabilizers were found to be less effective in the case of rape oil and still less so in the case of groundnut oil. Most of the stabilizers tried were ineffective towards cottonseed oil.

The extent of unsaturation of a given oil, its acidic constituents, the constitution of the component glycerides, and the unsaponifiable constituents determine whether or not the oil may be effectively stabilized. Out of the different types of substances tried, compounds having phenolic or amino groups attached to more than one benzene nucleus have been generally found to exert a strong stabilizing action.

Table 11 gives a summary of the quantitative data in the case of the most effective stabilizers so far found for the four oils studied.

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Utilization of Indian Vegetable Oils as Lubricants in Internal Combustion Engines

Part II

Introduction

The satisfactory operation of a properly designed I. C. engine depends primarily on the characteristics of the fuel as well as of the lubricant. Extensive research work has been carried out on the development of suitable fuels for use in aircraft and other high compression engines and suitable laboratory tests have been devised which reproduce to a reasonable degree of accuracy the behaviour of fuels in actual service. Similarly, work on mineral lubricating oils, for I. C. engines has led to the development of improved methods of refining and treatment which, in conjunction with a number of laboratory tests and actual field or bench tests in engines, has resulted in markedly improving the qualities of mineral lubricating oils, now available in all parts of the world. No systematic work, on the other hand, appears to have been done on the development of vegetable oil blends as lubricants for use in I. C. engines, although some attempts, as referred to in the first part, have been made by certain workers to use either mixtures of mineral and vegetable oils or vegetable oils as such, mostly without the addition of anti-oxidants or stabilizers.

One of the main reasons why countries, which are deficient in mineral oil supplies but are comparatively rich in vegetable oil resources, have not taken up the problem appears to be that vegetable oils, being mainly glycerides of unsaturated fatty acids, as distinct from the mineral lubricating oils which are mostly mixtures of saturated hydrocarbons, are relatively unstable and liable to oxidation, polymerization and cracking resulting in the formation of sludges and gummy substances, which are detrimental to the proper functioning of the engines.

Against the serious disadvantages mentioned above there is however, a valuable property, known as oiliness, which is possessed by fatty oils[1, 2] to a marked degree and which makes them eminently suitable as lubricants under conditions which render the existence of full fluid films between bearing surfaces difficult. It is now well established that piston friction[3] accounts for practically 70 per cent of the total friction losses in an engine and, therefore, the study of cylinder lubrication has engaged the serious attention of physicists,

engineers and chemists in increasing numbers, and exhaustive research work on cylinder lubrication has been carried out by several organizations, particularly by the Research Departments of the Institution of Automobile Engineers, London and engineering bodies.

The question is whether the lubrication between the cylinder wall and the outer surface of the piston ring is of the fluid or of the boundary type. Different answers are given to this question by different workers in the field, but it is generally recognized that both types of lubrication[4, 6, 7] with gradual change from one type to the other, exist between the cylinder wall and the piston ring. There is definite evidence[5] to show that the lubrication between the cylinder and the piston tends towards the boundary type near the top dead centre, where the piston speed is low and the high gas pressure exerted behind the ring largely increases the normal pressure between it and the cylinder wall. To a less degree, the same thing occurs near the bottom dead centre at the end of the stroke, where the piston velocity again drops to zero. During the central part of the stroke, where the piston speed is high, full fluid film lubrication is liable to be established and the frictional force is largely unaffected by the surface condition of the metal and the oil. To what extent and at what points these conditions are likely to prevail will depend to a large extent on a number of variables, such as the amount of oil supplied, the speed, temperature, load, etc. There will, however, be some boundary lubrication in the vicinity of the dead centres owing to the very low velocity of the piston at these parts of the stroke. Boundary lubrication conditions may also obtain at the moment of starting and stopping the engine or when the viscosity of the oil is too low or excessively reduced by heat preventing the formation or persistence of a sufficiently thick layer of the lubricant.

Dickinson and Bridgeman[7] have aptly observed that modern conditions of load, speed and viscosity approach the critical point between viscous and boundary lubrication. It may, therefore, be definitely concluded that, though by far the major portion of the friction loss in an internal combustion engine is caused by the fluid type of friction, the safety of the engine from undue wear or even seizure cannot, by any means, be independent of the characteristics of the oil under boundary conditions. The work of Langmuir, Adam and a number of other investigators[8, 9, 10] has thrown a flood of light on the mechanism of lubrication under the above conditions, and it has been proved beyond doubt that fatty oils, in general, on account of their superior oiliness, consequent on the formation of adsorbed films on bearing surfaces by virtue of their polar groups, develop less friction, and to that extent conditions are favourable for reducing wear and preventing bearing seizure.

Prior to 1933, it was generally assumed that direct abrasion

between piston and cylinder walls was wholly responsible for cylinder wear. The investigations of the Institution of Automobile Engineers, London[11, 12], have definitely shown that wear is also, to a large extent, the result of corrosion from the products of combustion and that the major part of the wear occurs during the starting and the warming up period before the cylinder walls have a chance of attaining a temperature sufficient to prevent condensation of water on the surface. This is confirmed by the work of other investigators. Everett and Stewart[13] and Keller[14] carrying out the determination of wear by the iron content of crank case oil found that iron was removed from the engine practically four times as fast in the first hour as in the succeeding five hours.

It has also been proved by the investigations of the Institute of Automobile Engineers[15] that though pure paraffin is a poor lubricant and gives inadequate protection against corrosion under cold running conditions, the presence of a small percentage of fatty acids or oils greatly improved its corrosion-resistance with consequent reduction in wear. It is, therefore, evident that the small percentage of fatty oils, which is added to the mineral lubricant, serves as an effective protection from the corrosion products of combustion by forming a strongly absorbed film on the surface of the cylinder. If, however, the mineral oil is completely replaced by a vegetable oil, it remains to be seen whether the absorbed film will be any more effective in affording protection against the products of combustion and the products of oxidation and decomposition, which are likely to be acidic in character.

Requirements of a Good Lubricant

Some of the essential requirements which a lubricant must satisfy may be stated as follows :

(1) It must remain stable and undergo as little change in its physical and chemical characteristics as possible under the widest range of operating conditions prevalent in internal combustion engines of varying types and capacities.

(2) It should be free from inorganic acidity and should not show more than a very small degree of organic acidity.

(3) It should prevent the wear of the bearing parts and reduce friction losses to a minimum even under boundary conditions of lubrication.

(4) It should serve as an effective protection against corrosion wear, particularly during low temperature running conditions.

(5) Oil consumption should be minimum consistent with adequate lubrication.

Stability—It is well known that vegetable oils are less stable than mineral oils. When, therefore, the fact that the temperature of the

cylinder walls may reach a value well over 200°C., and that the oil film on it may also be subjected to a scorching temperature of 1,000° —2,000°C. during every alternate revolution, leading to oxidation and cracking of the oil film, is taken into consideration, the difficulty of using vegetable oils as lubricants under the above conditions of operation would be apparent. It must, however, be borne in mind that untreated mineral oils, which are mixtures of hydrocarbon molecules of extreme complexity and variety, contain also from 20 to 40 per cent of unsaturated hydrocarbons[16] and it is only by the elimination of most of these unsaturated compounds by new and improved methods of refining, addition of suitable stabilizers and addition agents that the modern mineral lubricating oils of commerce have attained their present position. On the other hand vegetable oils are of comparatively known and constant composition. So it is considered that with suitable stabilisers and addition agents, it should not be impossible to produce blends of vegetable oils, which would compare favourably with the various grades of existing lubricants.

Acidity—The presence of free inorganic acids in mineral oils is very rare, although traces of sulphuric acid may be left after refining. Free fatty acids are, however, almost always present in compounded lubricating oils in small amounts, and free petroleum acid may also be present in traces. In the case of vegetable oils, it should also be possible by suitable refining methods to produce a blend having a very low acid value, and the possibility of development of further acidity in storage or use might be taken care of by the choice of suitable stabilizers.

Wear (abrasion)—With regard to wear, while there is hardly anything to choose between vegetable oils and mineral oils so long as a full fluid film is maintained, vegetable oils, as previously explained, owing to their active polar groups act as effective boundary lubricants and, therefore, cause less wear in those parts where this condition is likely to obtain and ensure a longer life of the engine.

Corrosion—The effect of corrosion, particularly under cold running conditions, has already been discussed (see page 35), and it has been pointed out how far vegetable oils are likely to be able to withstand these conditions as well as mineral oils.

Consumption—Vegetable oils are non-volatile in character, and, if suitably stabilized so as to prevent formation of carbonaceous and gummy substances or sludge, are expected to show less or, at least, no higher consumption than mineral oils.

Laboratory Tests

Laboratory tests for determining the suitability of a lubricating oil for a particular purpose or for identifying the source of the oil may be divided into the following two classes.

(1) Those for measuring the oxidation stability of an oil.

(2) Those for determining the physico-chemical characteristics, of which the following may be mentioned : (i) acid value, (ii) viscosity and viscosity index, (iii) carbon residue, (iv) pour point, (v) flash point, (vi) specific gravity, (vii) oiliness, (viii) saponification value, and (ix) iodine value.

Oxidation tests—Stability is the most important requirement of a lubricant for internal combustion engines. It is usually measured by the changes in the characteristics of the oil, such as viscosity, acid value, carbon residue and sludge formed, on subjecting it to oxidation tests. Various laboratory oxidation tests have been proposed from time to time to reproduce what may happen under actual engine conditions, but none, so far, can be considered as giving exact information on the changes likely to take place in the characteristics of the oil, although the Air Ministry Oxidation Test, Indiana Test or the Sligh Test furnishes information which may serve as a valuable guide in this respect. The laboratory oxidation tests fail to assess the quality of a lubricating oil, chiefly because they cannot possibly reproduce the various changes in operating conditions which an engine has to encounter in actual service and the changes in the characteristics of the oil, particularly the formation of the different types of sludge which is governed by the conditions of operation, that is, whether an engine is running under low temperature conditions which result mainly in the formation of the emulsion[17] type of sludge, or under normal or high temperature conditions which result in what is called 'oxidation sludge.'

For the purpose of the present investigation, Air Ministry Oxidation Test, modified to accelerate the oxidation, was found to give fairly reproducible results, although of course, it can claim no better correlation with the actual engine tests than any other similar oxidation test.

Acid value—The determination of acid value is of particular importance in the case of vegetable oils, which are likely to develop free acids not only by oxidation and thermal decomposition under engine operating conditions, but also under storage conditions. Besides, it is not only the quantity of acids, but also the nature of acids, which is important in the corrosion of engine parts.

Viscosity and viscosity index—Of all the major requirements of a lubricating oil, the one that is directly related to the performance of a lubricant in actual service is the satisfactory viscosity-temperature characteristics, as it not only influences the losses in the various bearing parts, the rate of flow of oil and oil consumption, but also, the starting torque or the ease of starting, particularly during the cold weather. A satisfactory lubricant is one which shows a relatively small change in viscosity with temperature, so that once the viscosity is adjusted

to suit a specific engine design, there should be no difficulty in starting owing to high viscosity when the engine is cold. Nor should the reduction of viscosity as a result of high temperature during normal running be such as to cause rupture of the film. In the case of mineral oils, it is only by the development of the newer methods of refining and the selection of proper crudes and suitable addition agents that it has been possible to produce oils of sufficiently high viscosity index, while most of the vegetable oils, in the untreated condition, are appreciably better in this respect than even the treated mineral oils. In evaluating the performance of a lubricating oil, it is, therefore, of importance not only to determine the initial viscosity and viscosity-temperature characteristics of the oil, but also to carry out these determinations at intervals during the progress of the engine tests, in order to study the progressive deterioration of the oil as a result of oxidation, thermal decomposition or other chemical reactions.

Carbon residue—The deposits in the different engine parts, which are generally classified under the name of "Carbon" are generally formed by the oxidation and breakdown of the oil or sometimes by the incomplete combustion of the fuel in the combustion space.

The various factors which influence the formation of carbon deposits in gasoline engines have been summed up by Gruse[18] as follows: (1) engine running conditions, (2) oil consumption, (3) time since cleaning, (4) amount of dust in air, (5) air-fuel mixture ratio, (6) engine design and condition, (7) characteristics of the fuel, and (8) characteristics of the oil.

It should appear from the numerous factors which influence the formation of carbon deposits in the various parts of an internal combustion engine that it is well-nigh impossible to devise any single laboratory test or group of tests which can correlate with the actual engine performance in this respect with any reasonable degree of accuracy. A number of physical and chemical tests, however, have been proposed from time to time for estimating the carbonizing tendency of the lubricating oils, the most important among them being the coking tests, such as Carbon residue or Conradson carbon and the Coke number of the Ramsbottom test, but there is material difference in the extent of correlation between the laboratory tests and the actual engine performance obtained by different workers. Another test which claims better correlation[19] is the Vacuum Distillation Test which measures the temperature of the 90 per cent distilled point at an absolute pressure of 1 mm. mercury. This test, however, cannot be directly applied to the case of vegetable oils which are fixed oils.

It may be pointed out that although some workers have found a good correlation between the above tests and the engine deposits in the case of oils of similar origin, others have failed to do so when testing oils from different sources or subjected to different treatments[20].

These deposits which vary in character from the hard asphaltic to the soft gummy type are found in: (1) combustion chamber, comprising the piston top and cylinder head, (2) shoulder and stems of the valves and valve seats, (3) underside of the piston, (4) piston ring grooves and ring lands, (5) piston ring slots and drain holes on the scraper ring groove.

The effect of excessive deposits on the various parts, as outlined above, is too well known to need any further elaboration. While mineral oils are not altogether free from the tendency of producing carbon, the problem of using vegetable oils as lubricants in an internal combustion engine is more complicated by the severity and complexity of operation in an engine and also by the fact that vegetable oils, in general, have a higher carbonizing tendency than most of the mineral lubricants.

Pour point—This test is carried out to determine the ability of an oil to flow at low temperatures. In view of the fact that some of the low iodine value vegetable oils, such as coconut oil, set at even ordinary winter temperatures, this value is of importance in deciding whether a particular oil could be used as a lubricant.

Flash point and specific gravity—These tests have their chief value in being useful for identifying an oil or aiding the refinery control. They do not, however, give any indication of the lubricating quality of an oil, although it would not be unreasonable to suppose that a higher flash point might mean greater resistance to burning on cylinder walls during the explosion stroke.

Oiliness—The significance of this property in a lubricating oil has already been dealt with at length, but while its determination is of importance in the case of mineral oils, which are generally deficient in this property, it was not considered necessary to undertake the determination of this property in the present investigation in view of the markedly superior oiliness possessed by fatty oils in general.*

Saponification value—The saponification value of an oil serves as a valuable guide to its identification or to its purity determination. Although the value is not fixed but varies within narrow limits, it is useful for purposes of identification in conjunction with other characteristics. In the present investigation, the determination of

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* Oiliness has recently been measured by the slider method for brass and mild steel surfaces under different loads for mahua, domba and hongay (Thiagarajan & Srikantan[21]).

this characteristic at different stages of the run served the useful purpose of indicating the rate of decomposition or oxidation and/or polymerisation of the oils. A decrease in the saponification value indicates the formation of hydrocarbons or other neutral products and a rise in the saponification value indicates the formation of more acidic components.

Iodine value—Although iodine value is not considered to be a very reliable guide to unsaturation in the case of mineral oils, it is considered to be sufficiently indicative of the degree of unsaturation in the case of fatty oils[22]. The determination of this value in the case of vegetable oils may, therefore, be considered to be of importance as it throws some light on the extent of saturation acquired by the lubricant at different stages during the progress of the run.

Engine Tests

No single physical or chemical test or group of tests has been developed up till now, to predict the behaviour of an oil under actual service conditions even approximately. The actual engine test is, therefore, considered to be the only reliable means of determining the suitability or otherwise of a lubricating oil. Engine tests may comprise either actual road tests or bench tests under carefully controlled conditions to represent the average road conditions so far as the average operating temperature, load and speed are concerned. When, however, it is realized that the range of operating conditions encountered in actual service is practically unlimited, one might think that the results of tests under these conditions would hardly apply to those obtained with bench tests. On the other hand, field tests giving dependable and reproducible data are too expensive and rather difficult to carry out. Under the circumstances, dynamometer tests under carefully controlled conditions are generally adopted and considered to be good enough for evaluating the performance of an oil under service conditions.

The problem, therefore, reduces itself to the folowing.

(1) Development of suitable vegetable oil and mineral—vegetable oil blends of required viscosity and selection of suitably stabilized ones for engine tests, on the basis of oxidation and other laboratory tests on individual oils as well as blends.

(2) Development of suitable engine equipment.

(3) Standardization of various test-conditions.

(4) Assessing the results of tests on various vegetable oil blends in comparison with reference lubricants (such as a reputed make of mineral oil).

Development of blends—Selection of test material was based on results recorded in Part I. Accordingly, it was decided to confine

engine tests, in the initial stage, to castor and groundnut oils and prepare their mixtures in varying proportions to adjust the viscosity within the limits specified by B. S. Specification No. 210—1930 for medium lubricating oils for internal combustion engines, recommended by the makers of the engines in which tests were carried out. The two mixtures (castor oil 60 per cent, groundnut oil 40 per cent and castor oil 40 per cent, groundnut oil 60 per cent) which satisfied the specification requirements as regards viscosity were again submitted to a series of modified oxidation tests after the addition of effective stabilizers.

The effects of various stabilizers on the two blends are shown in Tables 1 and 2.

It is clear from Tables 1 and 2 that the blend containing 60 per cent of castor oil and 40 per cent of groundnut oil showed, in general, better stabilization than that containing 40 per cent of castor oil and 60 per cent of groundnut oil. The former blend was therefore adopted as a standard mixture for engine tests. In order, however, to obviate any possible risk or damage to the engine, it was considered desirable to try mineral oil and castor oil mixtures to start with, and then gradually to substitute vegetable oil blends. This necessitated the development of a suitable process for rendering castor

TABLE 1—Effect of stabilizers on a 60:40 blend of castor and groundnut oils when subjected to modified Air Ministry Oxidation Test

No.	Stabilizer	Quantity of stabilizer %	Viscosity at 100°F. (c.s.)	Viscosity increase ratio	Acid value	Conradson carbon residue	Remarks
1	Original (unblown)	..	122.1	..	2.5	0.27	
2	No stabilizer ..	..	893.8	7.3	4.2	0.97	
3	α-Naphthol ..	1.0	424.9	3.5	4.0	1.29	
4	α-Naphthol and ..	0.4	428.4	3.5	4.5	1.0	
	β-naphthol ..	1.2					
5	α-Naphthol and ..	0.4	483.4	3.9	2.4	1.5	Slight brownish
	pyrogallol ..	0.6					black deposit
6	α-Naphthol and ..	0.5	482.0	3.9	4.3	1.27	Slight black deposit
	hydroquinone ..	0.5					
7	Hydroquinone and	0.5	425.5	3.5	4.2	1.26	Black deposit
	β-naphthylamine ..	0.5					
8	α-Naphthol and ..	0.4	470.7	3.85	3.1	1.1	do.
	p-phenylenediamine	0.6					
9	α-Naphthol, ..	0.2	472.1	3.86	5.05	1.43	do.
	β-naphthol, ..	0.2					
	hydroquinone, ..	0.2					
	β-naphthylamine and	0.2					
	p-phenylenediamine	0.4					
10	α-Naphthol, ..	0.4					
	hydroquinone and	0.3	495.4	3.74	4.4	1.1	Black deposit
	β-naphthylamine ..	0.3					
11	α-Naphthol and ..	0.4	546.8	4.5	3.64	1.35	
	benzidine ..	0.6					
12	α-Naphthylamine ..	1.0	442	3.6	4.8	1.22	
13	β-Naphthylamine ..	1.0	454	3.7	4.4	1.25	
14	α-Naphthylamine and	0.6	451	3.7	4.4	1.24	
	β-naphthylamine ..	0.4					
15	α-Naphthylamine and	0.4	448	3.65	4.3	1.3	
	β-naphthylamine ..	0.6					
16	p-Toluidine ..	1.0	541	4.43	3.6	1.17	

TABLE 2—Effect of stabilizers on a 40:60 blend of castor and groundnut oils when subjected to modified Air Ministry Oxidation Test

No.	Stabilizer	Quantity of stabilizer %	Viscosity at 100°F. (c.s.)	Viscosity increase ratio	Acid value	Conradson carbon residue	Remarks
1	Original (unblown)	..	83.7	..	2.5	0.29	
2	No stabilizer ..	..	687.1	8.2	4.2	1.03	
3	α-Naphthol ..	1.0	352.3	4.2	4.1	1.15	
4	α-Naphthol and ..	0.4	356.5	4.2	4.2	0.89	
	β-naphthol ..	0.2					
5	α-Naphthol and ..	0.4	423.4	5.0	2.1	1.41	Brownish black deposit
	pyrogallol ..	0.6					
6	α-Naphthol and ..	0.5	360.8	4.3	4.0	1.0	Slight black deposit
	hydroquinone ..	0.5					
7	Hydroquinone and	0.5	355.8	4.2	4.4	1.23	Black deposit
	β-naphthylamine ..	0.5					
8	α-Naphthol and ..	0.6	443.9	5.3	2.9	1.0	Considerable black deposit
	p-phenylenediamine						
9	α-Naphthol, ..	0.2					
	β-naphthol, ..	0.2					
	hydroquinone, ..	0.2	427.3	5.1	4.6	1.4	Black deposit
	β-naphthylamine and	0.2					
	p-phenylenediamine	0.4					
10	β-Naphthol, ..	0.4					
	hydroquinone and	0.3	377.9	4.5	4.3	1.4	do.
	β-naphthylamine ..	0.3					
11	α-Naphthol and ..	0.4	464.9	5.5	4.4	1.39	
	benzidine ..	0.6					

oil miscible with mineral oil. Although a number of such processes was developed there were practical difficulties in adopting them; for this reason, and also for economy, it was decided ultimately to introduce a certain percentage of groundnut oil which would render castor oil miscible with mineral oil without any special treatment. One such blend which was quite stable and did not separate on standing was a mixture containing 40 per cent of groundnut oil, 40 per cent of castor oil and 20 per cent of mineral oil "A". The resulting viscosity was also well within the limits of viscosity for medium lubricating oils for internal combustion engines. The engine test was, therefore, initiated with this blend in conjunction with 2 per cent β-naphthol, which, on the basis of laboratory tests carried out so far, gave an indication of the likelihood of satisfactory behaviour in engine tests. This was followed by blend 2, which was composed of 60 per cent of blown groundnut oil and 40 per cent of mineral oil "A" with 2 per cent β-naphthol and 0.2 per cent tin-naphthenate as stabilizers. The results of engine tests on These blends, as shown later on, being generally satisfactory, several pure vegetable oil blends were developed as a result of extensive laboratory tests on individual oils and blends with various stabilizers. The composition of the various blends tried and the results of modified Air Ministry Oxidation Tests are given in Tables 3 and 4 respectively.

TABLE 3—Composition of blends

Blend	Mineral lubricant "A" %	Castor oil %	Ground-nut oil %	Rape oil %	Stabilizer	Quantity of stabilizer %	Remarks
1	20	40	40	..	β-Naphthol	2	Unrefined vegetable oils
2	40	..	60 (blown)	..	β-Naphthol and Tin naphthenate	2 0.2	do.
3	..	60	40	..	α-Naphthol	1	Unrefined oils
4	..	60	40	..	No stabilizers		do.
5	..	60	40	..	α-Naphthol	1	*Refined oils; soap content—0.1117 p.c.
6	..	60	40	..	α-Naphthol	1	Refined oils; soap content—0.0195 p.c.
7	..	60	40	..	α-Naphthylamine	1	Refined oils
8	..	60	40	..	α-Naphthylamine Chromium oleate	1 0.1	do.
9	..	50	..	50	α-Naphthylamine	1	do.
10	..	50	..	50	β-Naphthylamine Diphenylamine	0.5 0.5	do.

*The refining of oils was carried out by the ordinary alkali process, the soap being removed by repeated washing with hot water.

TABLE 4—Results of Modified Air Ministry Oxidation Test on mineral and vegetable oil blends

Blend	Viscosity increase ratio	Acid value		Conradson carbon residue	
		Initial	Final	Initial	Final
1	5.5	..	..	0.35	0.97
2	5.3	..	..	0.56	1.27
3	3.5	2.5	4.0	0.27	1.29
4	7.3	2.5	4.2	0.27	0.97
5	3.8	0.86	2.6	0.27	1.58
6	3.9	0.88	3.5	0.22	1.47
7	4.4	1.0	3.1	0.18	1.56
8	4.0	1.1	3.4	0.21	1.21
9	4.6	1.2	4.4	0.20	0.96
10	4.8	1.6	4.1	0.22	1.1
Mineral lubricant "A"	1.08	0.0	0.5	0.21	0.26
Mineral lubricant "B"	1.59	0.1	1.5	0.08	1.90

Exerimental Plants

With a view to obviating any risk or damage to commercial engines in which the severity of operating conditions is bound to be excessive, it was planned to carry out preliminary engine tests in a single cylinder 3 h.p petrol engine and to subject only those blends that behaved satisfactorily in this unit to more severe operating conditions in a 16 h.p. 4-cylinder Morris industrial petrol engine.

The description of the engines, and their auxiliary equipment is given below :

(1) 1.5 *kW. 'Lister' Petrol Engine-Dynamo Set*

This unit consisted of a 3 B.h.p. vertical single cylinder 4-stroke water-cooled petrol engine, 4 in. bore and $4\frac{3}{8}$ in. stroke, rated at 700 r.p.m. and directly coupled by means of a flexible coupling, to a 110 volt compound wound d.c. generator of the enclosed ventilated

type, both being mounted on a cast iron bed plate. The engine was delivered fitted with a Lister Patent flood-proof type carburettor, a Lister Patent centrifugal type of governor and high tension magneto ignition system. The jacket cooling arrangement comprised a radiator cooled by a fan, driven from the shaft by a belt.

The lubrication of the bearing parts with the exception of main bearings is effected by means of splash from the oil trough at the bottom of the crank case, the latter being lubricated by oiler rings dipping into the same trough.

The engine was loaded by the generator, the output of which was arranged to be dissipated in a suitable water cooled resistance through a switch board with electrical control instruments.

In order to record the running temperature of the crank case oil, a mercury-in-glass thermometer was inserted through a hole drilled in the crank case drain hole plug. A similar thermometer was inserted through the top cover of the radiator for measuring the temperature of the cooling water which was kept constant at 205 $\pm$ 2°F. during these investigations. The temperature control was effected by putting the radiator fan out of action by removing the belt between the fan pulley and the shaft, admitting a controlled stream of cold water into the inlet side of the cylinder jacket and letting a controlled quantity of hot water overflow through the radiator overflow tube.

(2) *Morris Industrial Engine-Dynamometer Set*

This unit consisted chiefly of a 16 h.p. Morris industrial petrol engine coupled to an electric dynamometer (Fig. 2).

The engine was a 4-cylinder petrol engine having the following specifications : Rated power, 16 h.p.; rated speed, 1,500 r.p.m.; bore, 2.75 in.; stroke, 4.0 in.

The lubrication of the crank-shaft bearings is effected by a pressure feed system, whereas the lubrication of all other internal parts is provided for by splash from the oil trough. The engine as supplied was equipped with the following :

(*i*) One centrifugal water circulating pump on the water jacket outlet.

(*ii*) One spring loaded centrifugal type of governor with speed control device which regulates the carburettor throttle and which is designed to maintain the speed constant at all loads.

The engine which was of the commercial type was converted into an experimental unit by introducing certain modifications with a view to running it under strictly controlled conditions. The modifications included the following items :

(1) The radiator which was mounted close to the engine on the same channel base was dismantled and installed outside the laboratory.

It was connected to the outlet of the circulating pump and the inlet of the cooling water jacket by means of $1\frac{1}{2}$ in. pipes.

(2) An electric fan was provided for cooling the radiator and adjusting the temperature of the circulating water, the speed of the fan being controlled from inside the laboratory by means of a rheostat mounted on the switchboard.

(3) Two thermometer pockets (Fig. 1) were provided, one at the inlet and the other at the outlet of the cooling water jacket.

(4) In order to maintain the temperature of the intake mixture constant a 1.5 kW. electric heater was introduced into a re-entrant type of manifold between the carburettor and the intake manifold of the engine (Fig. 1). The heater was provided with a three-heat switch and a rheostat and ammeter mounted on the switchboard for accurate temperature control, the temperature being indicated by a thermometer located in a pocket provided at the intake port.

(5) One neon tube spark ignition indicator was provided to indicate the exact angle before T.D.C. at which the ignition took place.

(6) For adjusting the ignition angle, a convenient control was provided at the magneto.

(7) One oil pressure regulating valve designed to control the oil pressure in the lubrication system was installed in the oil feed line.

(8) One copper-constantan thermocouple, which was suitably insulated, was inserted through a suitably drilled hole along the length of the oil dipstick for measuring the crank case oil temperature.

The engine was coupled to the dynamometer through a flexible rubber-canvas disc coupling of the Hardy type. The dynamometer was of the usual trunnion mounted yoke type and was provided with two cantilever arms, one connected to a weighted centre-zero spring balance with hand wheel positioning gear, and the other to an oil dashpot which served to damp out the vibrations. The length of the lever arm was so designed that the torque delivered by the engine could be easily calculated by multiplying the spring balance reading with a simple multiplier. The unit was also provided with a revolution counter.

The engine-dynamometer assembly was mounted on a pair of channel pieces, anchored to a reinforced concrete bed which was isolated from the laboratory floor by providing a clearance of $\frac{3}{4}$ in. between the bed and the floor all around and filling up the gap with pitch.

The dynamometer could be used as a motor for starting the engine or as a generator for delivering the power output to a load resistance through suitable measuring instruments (see Fig. 1 for electrical connections and other details).

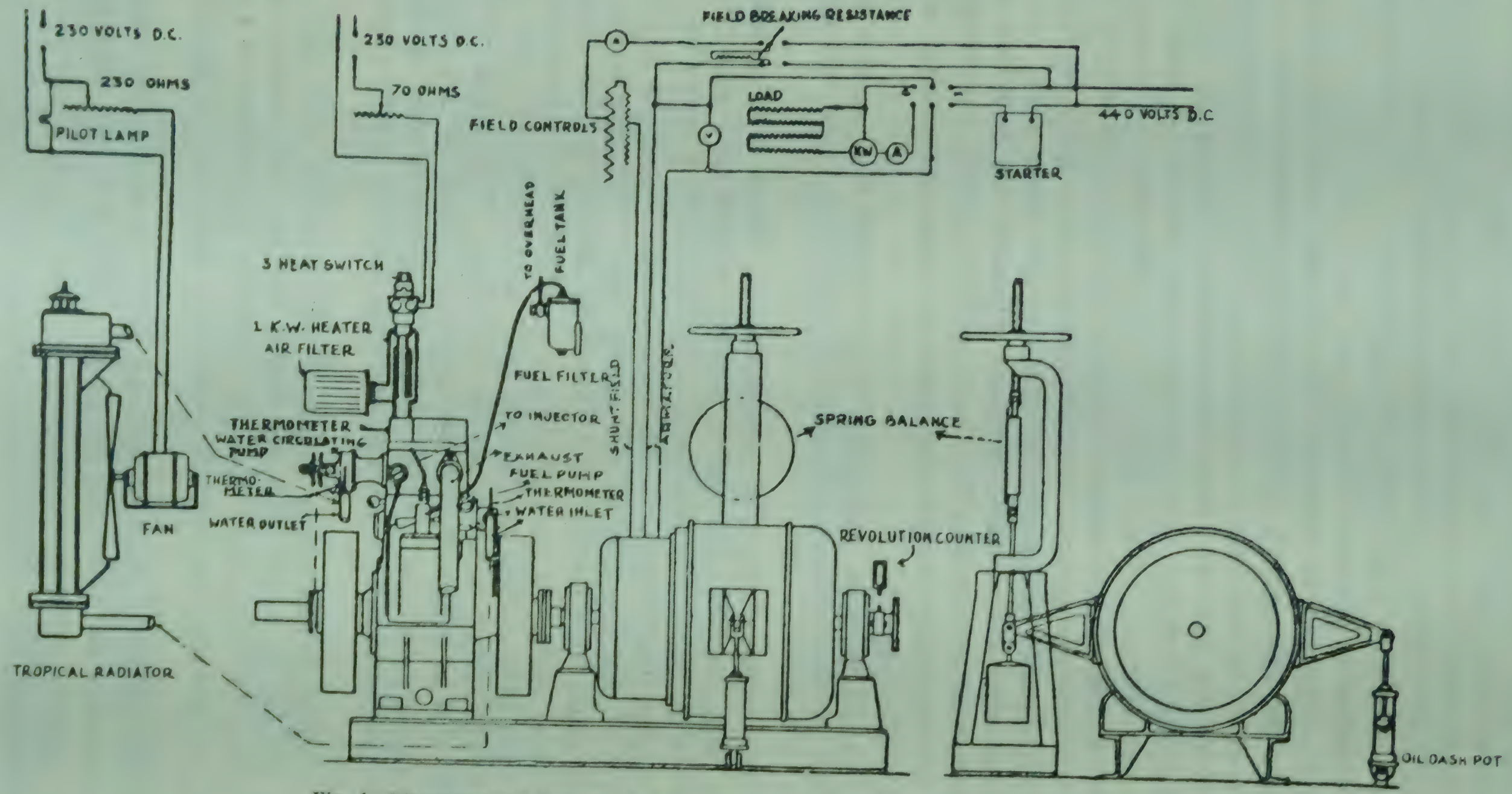


Fig. 1—Diagrammatic layout of experimental plant showing essential details of the Lister diesel engine, dynamometer and electrical control circuits

Experimental Procedure

Before undertaking actual engine tests on the various oils and blends, both engines, which were new, were run in for a sufficient length of time on mineral lubricating oil to ensure the proper bedding of bearings. For this purpose, the Lister Petrol Engine-Dynamo Set was run at approximately half load (0.75 kW.) and full speed (700 r.p.m.) for 30 hr., followed by another 100 hr. run at full load and full speed.

The total running in period for the Morris engine was 100 hrs., the first 50 hrs. run being conducted at approximately half load (7 B.h.p.) and three quarters maximum speed (1,200 r.p.m.) and the subsequent 50 hrs. run at approximately full load (14 B.h.p.) and full speed.

Standard conditions—At the conclusion of the running-in period, a series of trial runs was carried out, particularly with the Morris engine, for standardising the various operating conditions under which the engine tests could be conveniently carried out. As a result of these experiments, the following conditions were standardized.

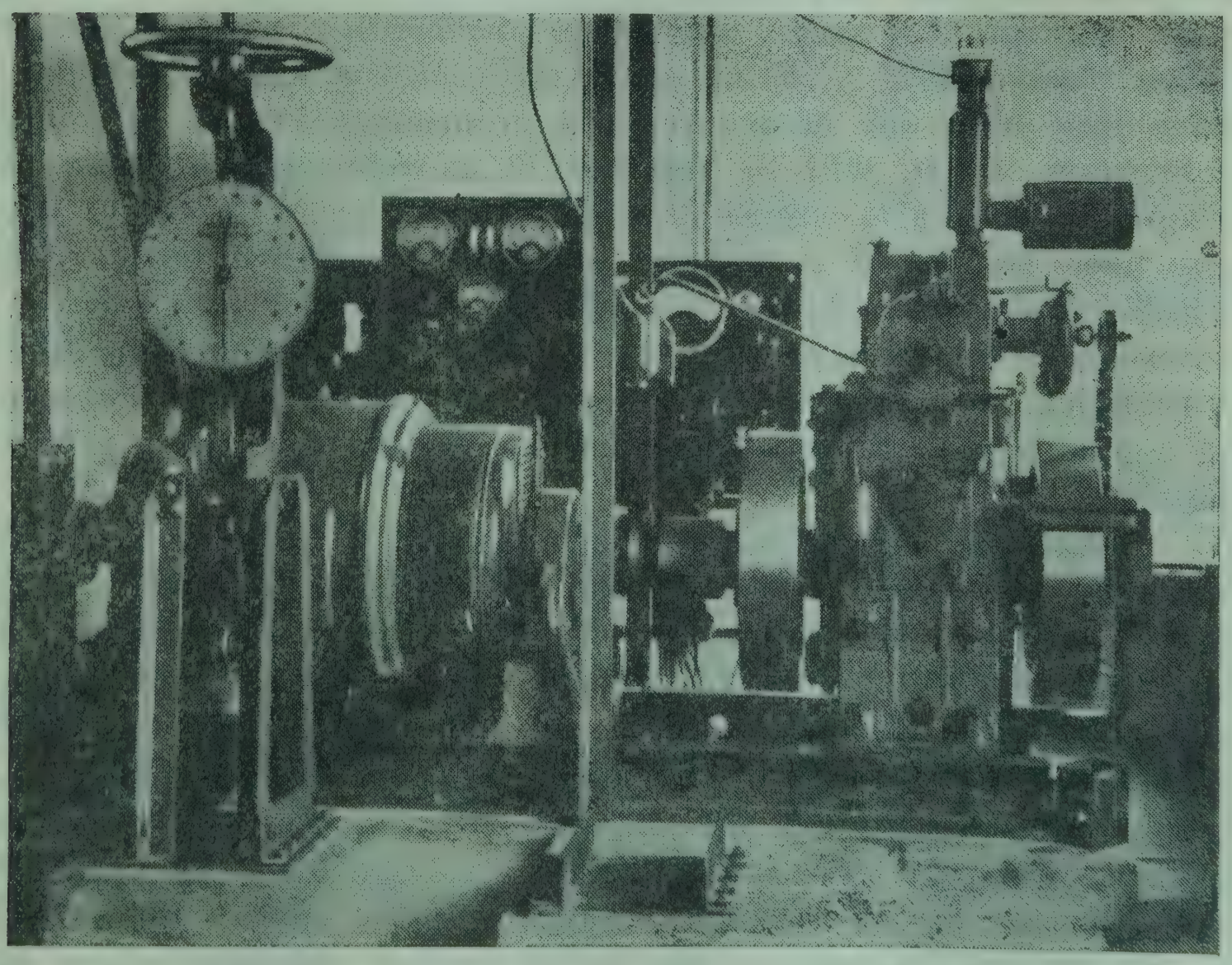


Fig. 2—General view of the engine dynamometer equipment with switch-board in the background

Lister Petrol Engine-Dynamo Set

(*i*)	Engine speed	700 r.p.m.
(*ii*)	Power output	1.8 h.p.
(*iii*)	Radiator water temperature	205° ± 2°F.

Morris Industrial Engine

(*i*)	Engine speed	1,500 r.p.m.
(*ii*)	Power output	14 B.h.p.
(*iii*)	Jacket water temperature at the outlet ..	170° ± 1°F.
(*iv*)	Spark advance	30° before T.D.C.
(*v*)	Intake mixture temperature	120° ± 1°F.
(*vi*)	Oil pressure	15 ± 2 lb. per sq. in.

The maximum power output available under these standardized conditions of operation averaged at approximately 14 B.h.p. as against the rated output of 16 B.h.p. specified by the makers. This is approximately what may be expected due to power reduction caused by the heating of the intake mixture to a high temperature and also maintaining the jacket water temperature at a fairly high value.

Standardization runs—After standardizing the various operating conditions, both the engines were opened up for thorough examination of the various parts and measurement of cylinders, pistons, bearings, etc., with a view to determining the wear and other changes that might take place as a result of subsequent runs. After reassembling, a 100 hr. standardization run was undertaken on each unit with one of the reputed proprietary brands of mineral lubricants, which will be referred to as reference lubricant "A". Engine test was also carried out with another mineral lubricant which has been designated as mineral lubricant "B". In order to obtain results of adequate precision standardization runs were carried at intervals to take into account the variation of test conditions due to mechanical changes and wear of the engine parts to enable the results of engine tests at different stages of the investigation to be properly assessed.

Make-up oil—Prior to the commencement of each day's run, the make-up oil was added to bring the level of the crank case oil in the Morris engine to a fixed mark on the dip stick, as recommended by the makers of the engine. In the case of the smaller engine (Lister), the make-up oil was added till the oil in the trough just overflowed. Some inaccuracy exists in the make-up oil figures for the smaller engine due to some of the oil used for lubricating tappets and governor finding its way into the crank case, but this is not considered to be serious, as the ultimate suitability of the various blends is to be determined by tests in the larger engine (Morris) where this possibility is practically ruled out.

Sump oil temperature—The equilibrium temperature of the crank case oil was recorded daily during the progress of the engine test by means of a copper-constantan thermocouple.

Motoring test—In order to determine the progressive changes, if any, in frictional losses owing to alteration in characteristics of the oil under the operating conditions, a motoring test was periodically carried out at the end of a day's run when the engine was thoroughly hot and the operating conditions stable. The change-over from generating to motoring was effected with as little delay as possible and without any effective change of speed, care being taken to cut off the fuel supply and to switch off the ignition as soon as the carburettor ran dry.

Sampling of crank case oil—In order to determine the changes in physical and chemical characteristics of the oil, as also the iron content (both in solution as well as in the insoluble residue along with sludge) during the progress of the run, 50 c.c. samples of the crank case oil were drawn at intervals of 25 hrs. approximately. The sampling was done by means of a pipette during the run or immediately after it before the sludge content of the oil or other suspended matter had a chance of settling down, in order that the sample was thoroughly representative of the main bulk of the crank case oil.

Experimental Results

The results of engine tests with various blends developed in this laboratory, as well as those with the reference lubricants are summarized under the following two heads :

(i) Preliminary engine tests, i.e. tests carried out in the 1.5 kW. Lister petrol engine-dynamo set.

(ii) Final engine tests, i.e., tests carried out in the 16 h.p. Morris industrial engine-dynamometer set.

Preliminary Engine Test

In Table 5 are summarised the variations in the more important characteristics of the oils and blends with engine operation, which give an indication of the oxidation and thermal stability of the oils under engine operating conditions.

Variations in some minor characteristics of the oils and blends are also included in the Table.

These variations, though not important from the point of view of judging the suitability of the oils as regards their lubricating quality, throw a good deal of light on the character of the changes taking place and, consequently supply data on which attempts to improve the quality of oils may be based.

In Table 6 are summarised the data which are directly or indirectly related to the friction losses and wear in the more important

TABLE 5—Changes in characteristics showing oxidation and thermal stability under engine operating conditions in (1.5 kW Lister Set)

(The three figures given under any head correspond respectively to 0,50 and 100 hrs. operation.)

Blend	Viscosity at 140°F. (c.s.) %	Rise in viscosity %	Viscosity index	Acid value	Conradson carbon residue %	Total amount of sludge g.	Crank case dilution %	Specific gravity at 100°F./100°F.	Saponification value	Iodine value	Ash %	Iron in ash %
Mineral lubricant "A" (1) ..	42.4	..	103	0	0.19	..	..	0.8710	0.45	13.1	0	..
	42.2	..	..	0.24	0.35	..	..	0.8682	2.20	15.4	0.016	..
	49.7	17.2	..	0.46	0.47	..	..	0.8696	2.39	15.0	0.042	..
Blend 1	41.8	..	..	4.15	0.30	..	..	0.9200	152.6	77.0	0	..
	45.5	..	..	5.10	0.85	..	..	0.9201	153.7	64.9	0.028	..
	46.5	11.2	..	5.45	0.92	..	..	0.9206	156.4	65.0	0.040	..
Blend 2	52.9	..	..	2.90	..	..	..	0.9079	128.6	55.0	..	..
	59.9	..	..	2.99	..	..	..	0.9106	141.3	52.4	..	..
	66.3	25.3	..	3.43	..	..	..	0.9138	145.2	52.1	..	..
Mineral lubricant "B" ..	41.3	..	57.9	0.08	0.08	..	..	0.9082	4.3	25.6	0	..
	44.4	..	62.3	0.28	0.16	..	..	0.9090	2.5	25.6	0.005	..
	46.7	13.1	83.5	0.30	0.16	1.50	..	0.9102	2.6	25.7	0.008	..
Blend 3	45.4	..	116.0		2.50	0.20		0.9389	179.4	92.7	0	0
	50.1	..	115.0	2.20	0.58	..	..	0.9383	179.0	83.6	0.034	16.3
	55.1	21.4	115.0	2.10	0.79	1.64	..	0.9423	186.3	83.3	0.056	20.0
Blend 4	45.6	..	116.0	2.34	0.20	..	..	0.9375	179.9	90.0	0	0
	78.8	..	115.0	3.60	0.88	..	..	0.9511	177.5	82.3	0.030	5.4
	144.2	216.2	110.0	5.09	1.40	2.34	..	0.9636	178.1	78.1	0.084	18.8
Blend 5	48.1	..	112.7	0.86	0.27	..	..	0.9406	182.6	88.0	0.009	0
	52.9	..	115.9	0.92	0.59	..	..	0.9433	192.0	86.0	0.017	5.7
	63.2	31.4	115.8	0.99	0.60	0.81	0.8	0.9491	198.2	84.2	0.044	10.2
Mineral lubricant "A" (2) ..	43.7	..	102.6	0.10	0.19	..	..	0.8760	0.16	13.8	0	0
	47.0	..	100.2	0.37	0.26	..	..	0.8794	3.15	17.2	0.014	2.2
	53.0	21.3	99.0	0.46	0.49	1.12	1.6	0.8805	3.80	23.1	0.017	3.6
Blend 6	46.5	..	114.5	0.88	0.22	..	..	0.9394	178.0	92.8	0.003	0
	51.0	..	117.0	1.00	0.43	..	..	0.9410	191.0	86.7	0.014	18.2
	55.9	20.2	114.5	1.20	0.58	1.32	0.8	0.9445	194.9	85.4	0.028	27.4
Blend 7	46.1	..	110.0	1.00	0.18	..	..	0.9391	190.0	92.1	0.004	0
	47.6	..	111.0	1.60	0.37	..	..	0.9399	197.0	85.8	0.014	14.5
	51.8	12.4	114.0	1.84	0.46	1.06	0.8	0.9403	193.3	86.2	0.021	19.2
Blend 8	48.3	..	114.0	1.07	0.21	..	..	0.9405	180.6	90.3	0.007	0
	53.4	..	113.0	1.80	0.40	..	..	0.9439	187.7	88.4	0.041	6.6
	54.0	11.8	113.2	2.00	0.59	1.94	..	0.9452	193.0	86.3	0.097	5.3
Blend 10	41.8	..	121.0	1.55	0.22	..	..	0.9333	178.5	97.2	0.001	0
	50.5	..	120.3	2.30	0.65	..	..	0.9389	184.2	97.9	0.022	1.0
	60.9	45.7	121.6	2.77	1.34	0.86	0.8	0.9437	197.8	94.0	0.060	2.1

engine parts as a result of the deterioration of the oil and abrasion or corrosion, or both.

In Table 7 are summarised the results of examination of the engine parts after each run and the nature and amount of deposits on piston, cylinder head, valves, etc., the deposits being carefully scraped off, collected and weighed wherever they occurred in appreciable amounts.

Results given in Table 5 and Fig. 3 indicate that the percentage rise in viscosity as a result of 100 hrs. run was maximum (216.2 per cent) in the case of Blend 4, containing no stabilizer and minimum in the case of Blends 7 (12.4 per cent) and 8 (11.8 per cent) without, of course, taking into consideration Blends 1 and 2 which were mineral-vegetable oil mixtures. The viscosity increase in the case of mineral reference lubricant "A"* in both the standardization runs was appreciably higher than that obtained with either of the vegetable oil Blends 7 and 8, although the crank case dilution after the second standardization run was twice that obtained with either of these

TABLE 6—Friction and wear characteristics of oils as brought out by 100 hrs. engine test in the Lister set

(The three figures given under each head correspond respectively to 0, 50 and 100 hrs. operation.)

Blend	Room temp. (°F.)	Max. crank case oil temp. (°F.)	Consumption of petrol per B.h.p. hr. (lb.)	Cylinder wear at limiting position of ring travel (in.)	Reduction in wt. of top piston ring (g.)	Iron in oil (p.p.m.)	Total iron content of crank case oil after 100 hrs. run (g.)
Mineral lub. "A"	96—84	140—131	..	0.0001	..	..	..
Blend 1 ..	90—79	138—126	1.31	Negligible	..	..	..
Blend 2 ..	85—73	136—124	1.4	0.0003	..	..	..
Mineral lub. "B"	96—85	140—135	1.25	0.0002	..	..	..
Blend 3	90—77	138—130	1.18	0.0005	0.0353	0 55 112	0.956
Blend 4	84—71	144—130	1.18	0.0002	0.0347	0 16.2 158.2	0.443
Blend 5	100—83	152—144	1.18	Negligible	0.0500	0 9.7 44.8	0.226
Mixeral lub. "A"	98—89	150—140	1.03	do.	0.0283	0 3.1 6.1	0.101
Blend 6	96—83	147—138	1.10	do.	0.0434	0 24.8 76.7	0.195
Blend 7	97—81	141—135	1.06	do.	0.0351	0 21.6 40.5	0.149
Blend 8	85—70	137—132	1.05	0.0003	0.0680	0 26.9 52.0	0.497
Blend 10	101—83	150—133	1.18	Negligible	0.0460	0 8.8 59.2	0.270

* Unless otherwise stated, the performance of various blends will be compared with that of reference lubricant "A" during the second standardization run (Run No. 8).

TABLE 7—Nature and extent of d

Blend	Piston top	Cylinder head	Total weight of deposits on piston top and cylinder head (g.)	Piston underside weight of deposit (g.)	Piston skirt	Top ring	
						Land	Gro
Mineral lubricant 'A"	1/3 Spongy; 2/3 hard	Hard	2.5	Slight deposit on top: rest of interior lacquered	Lacquered black at places	No appreciable deposit; lacquered black	No ap able d lacque black
Blend 1	1/2 Spongy; 1/2 hard	do.	3.6	Spongy and moist 2.5	do.	do.	do
Blend 2	Hard	do.	2.1	Spongy and moist 2.4	do.	Thin deposit at places	Thin, u form
Mineral lubricant "B"	1/3 Hard and 2/3 spongy	do.	0.58	Thick at top; rest of interior lacquered 1.0	do.	Lacquered black	Lacquer black
Blend 3	Thick on periphery; fairly hard	do.	3.2	Thick, partly soft and partly hard at top 1.8	do.	Thin, irregular	Thin, sti
Blend 4	2/3 Thick; 1/3 thin	do.	3.3	Thick, moist at top; rest of interior lacquered 13.2	do.	do.	Gummy
Blend 5	Thin, hard near the centre; thick round periphery	do.	1.4	Thin, granular at top; rest of interior lacquered 0.63	do.	Gummy deposit over ½ area; the other ½ clean	Partly t and pa thick, gummy
Mineral lubricant "A"	1/3 Thin, hard; 2/3 practically clean	do.	0.55	Thin, hard 1.0	do.	Thin, soft over ½ area; the other ½ clean	No app able de
Blend 6	¼ Thin, hard, brownish; ¾ practically clear	do.	2.5	Isolated spongy deposits at top; the rest of the interior lacquered	do.	Thin isolated deposits at places	Thin film
Blend 7	Central half free from deposit; other half partly resinous, brownish hard	Fairly hard, partly brownish	1.3	Thin, moist 0.52	do.	Thin over ¼ area; rest bright	Thin, uni form.
Blend 8	Central half free from deposit; other half thin, hard	Hard	0.98	Thin, moist at places 0.34	do.	Thin over a small area; remaining area bright	Thin, unif
Blend 10	½ Practically free from deposit; other ½ hard, easily removable	Fairly hard	0.77	Partly moist 2.31	do.	Practically ½ with thin deposit interspersed with bright spots; other ½ clean	Thin

n various engine parts after 100 hrs. run

Lower rings		Inlet valve		Exhaust valve		Remarks
Land	Groove	Stem	Shoulder and face	Stem	Shoulder and face	
o appreci-ble deposit; acquered lack	No appreci-able deposit; lacquered black	Part stained; isolated specks of carbona-ceous matter	Thin deposit	None; stained reddish	None; stained reddish	No clogging of drain holes or scraper ring groove. A few scraper ring slots clogged. Piston rings free in grooves
do.	do.	Part stained	do.	do.	do.	Only a few scraper ring slots clogged. Piston rings free in grooves
hin, uni-form	Thin, uni-form	do.	Appreciable; granular and gummy on shoulder only	Stained black	Stained black	do.
acquered black	Lacquered black	Thin	Thin	do.	do.	Piston rings free in grooves
Thin, sticky	Thin, sticky	Thin, granu-lar	Thin; granu-lar on shoulder	Stained reddish	Stained reddish	do.
Gummy (2nd) lacquered (3rd)	Gummy (2nd) lacquered (3rd)	do.	do.	Thin; part stained reddish	do.	A large number of scraper ring slots clogged. Top ring stuck; others free in grooves
Thin, uni-form	Thin, uni-form	do.	Fairly thick, soft and granular on shoulder, thin on face	do.	do.	A few scraper ring slots clogged. Top ring stuck
No appreci-able deposit, lacquered	No appreci-able deposit; lacquered	Fairly stained and partly covered with thin carbon	Thin	Stained reddish	do.	Piston rings free in grooves
Thin film	Thin film	Thin, a few granules at isolated points	Thin film on face and shoulders. Isolated granules on shoulder	do.	do.	A few scraper ring slots clogged. Piston rings free in grooves
Thin uni-form	Thin uni-form	Thin	Thin	do.	do.	A number of scraper ring slots clogged. Piston rings free in grooves
Second bright ex-cept for a small area, third covered with thin uni-form deposit	Thin, uni-form	Thin film, with gra-nules here and there	Thin film, shoulder covered will gra-nules at isolated points	do.	do.	Practically half the scra-per ring slots either par-tially or entirely clogged
Thin	Thin	Part stained; part granu-lated	Granulated over shoul-der; thin de-posit over face	do.	do.	Piston rings free in grooves

blends. The data, presented above, clearly demonstrate the marked effect of the addition of stabilizers in suppressing the various chemical reactions which lead to increased viscosity.

As regards the viscosity index (Fig. 4), it will also be seen that the vegetable oil blends, in general, are superior to the mineral oils. The changes in viscosity index with the progress of the run were slight and practically of the same order in the case of both vegetable and mineral oils.

Blend 4, the untreated blend, showed a sharp increase in acidity (Fig. 5) approximately after 25 hrs. run, the maximum increase in acid value being 2.75 as against 0.46 (first standardization run) and 0.36 (second standardization run) with the mineral reference lubricant "A", whereas the change in the acid value of the pure vegetable oil blends, as a result of stabilization, varied between 1.22 and 0.13. It is also interesting to note that Blend 3 showed a final decrease in acid value. So, even with regard to acidity, the effect of stabilizers is quite marked and some of the blends behaved better in this respect than the mineral oils.

As regards Conradson carbon residue (Fig. 6), although the vegetable oil blends and the mineral oils had more or less the same values initially, the vegetable oils, in general, showed a higher carbon residue increase than the reference lubricant "A", the change in this respect, as in others, being most marked in the case of the unstabilized Blend 4. The increase in Blends 5, 6, 7 and 8 may be considered to be of the same order as in the case of the reference lubricant "A".

Results of Table 5 and Fig. 8 indicate that practically 4 (Blends 2, 6, 8 and 10) out of the 7 vegetable oil blends showed an appreciable increase in saponification value. The saponification values of the remaining blends as well as of the reference lubricant "A" either remained nearly constant or showed a slight tendency to increase with the duration of operation. What is rather remarkable is that the untreated blend did not show any increase in saponification value, but, on the other hand, showed a slight tendency to decrease indicating thereby that the chemical reaction did not proceed beyond, perhaps the decomposition of the glycerides into fatty acids and neutral products.

Generally speaking, the engine operating conditions had the effect of increasing the acidic constituents as a result of complex chemical reactions, but this effect was more pronounced in the case of some of the stabilized blends.

The iodine values (Fig. 9) of all the vegetable oil blends decreased with the progress of the engine test, the minimum value being reached approximately between 70 and 80 hrs. operation. The most interesting feature that is brought out by the engine test

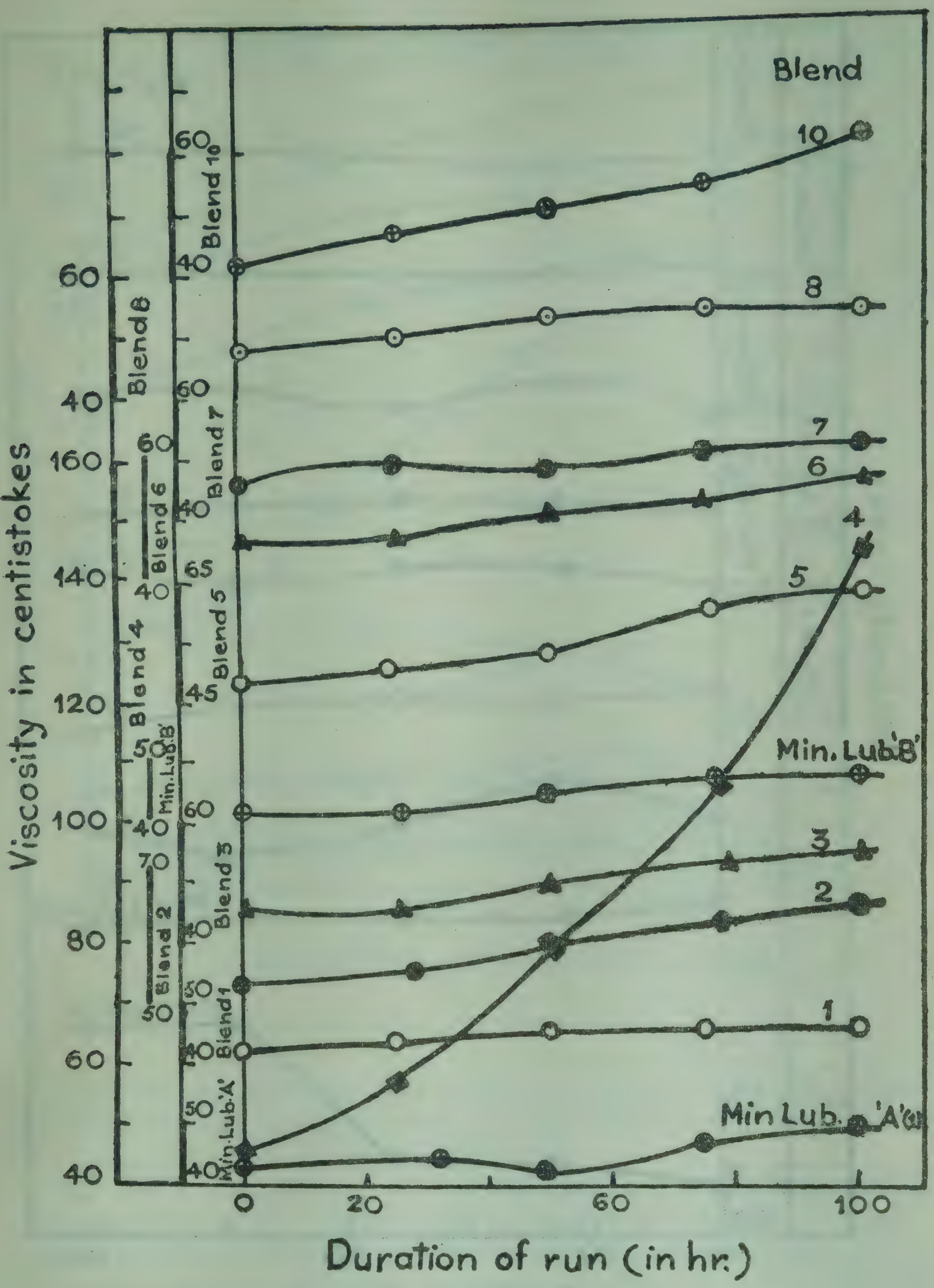


Fig. 3—Change of viscosity with duration of run (Lister Set)

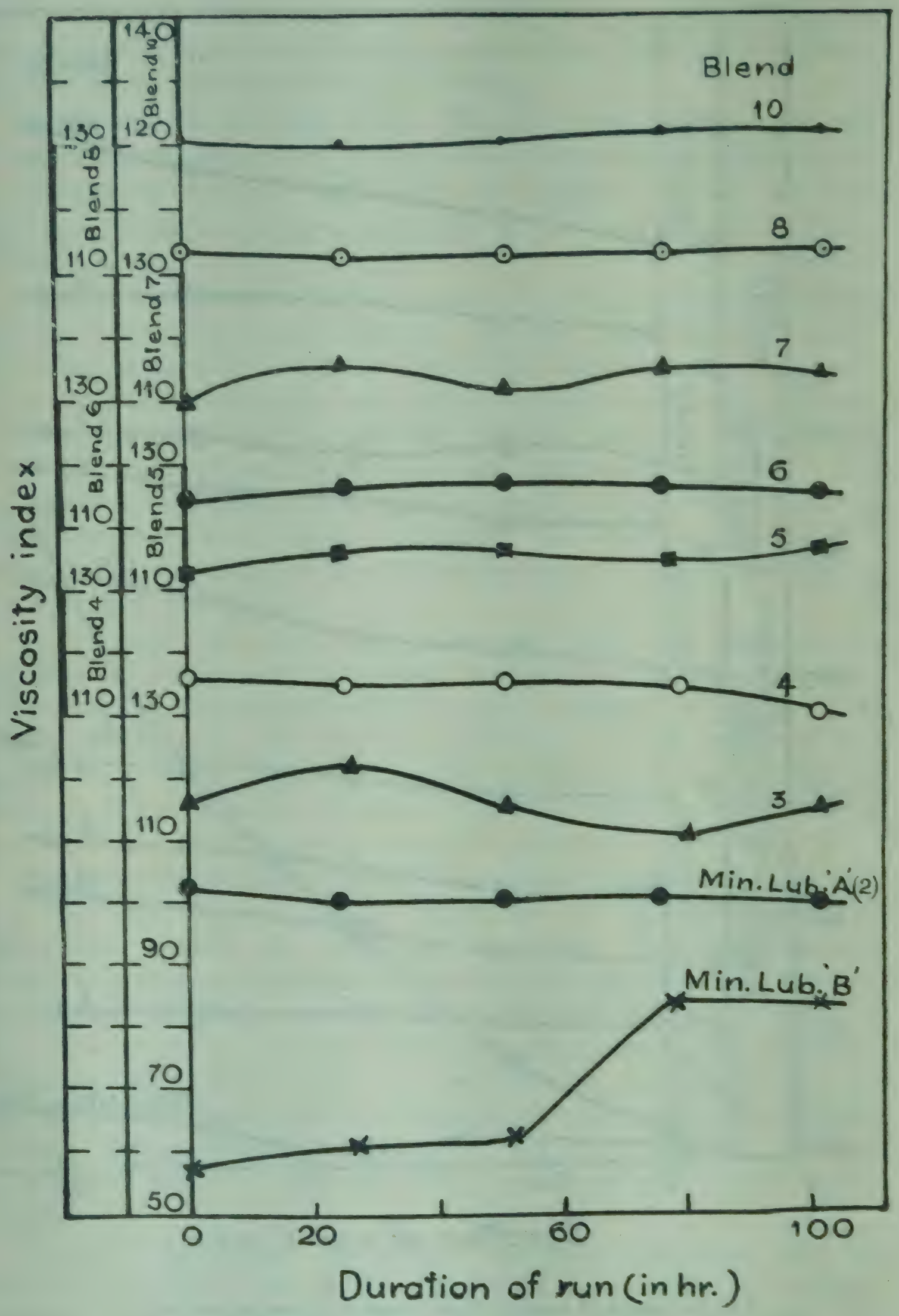


Fig. 4—Change of viscosity index with duration of run (Lister Set)

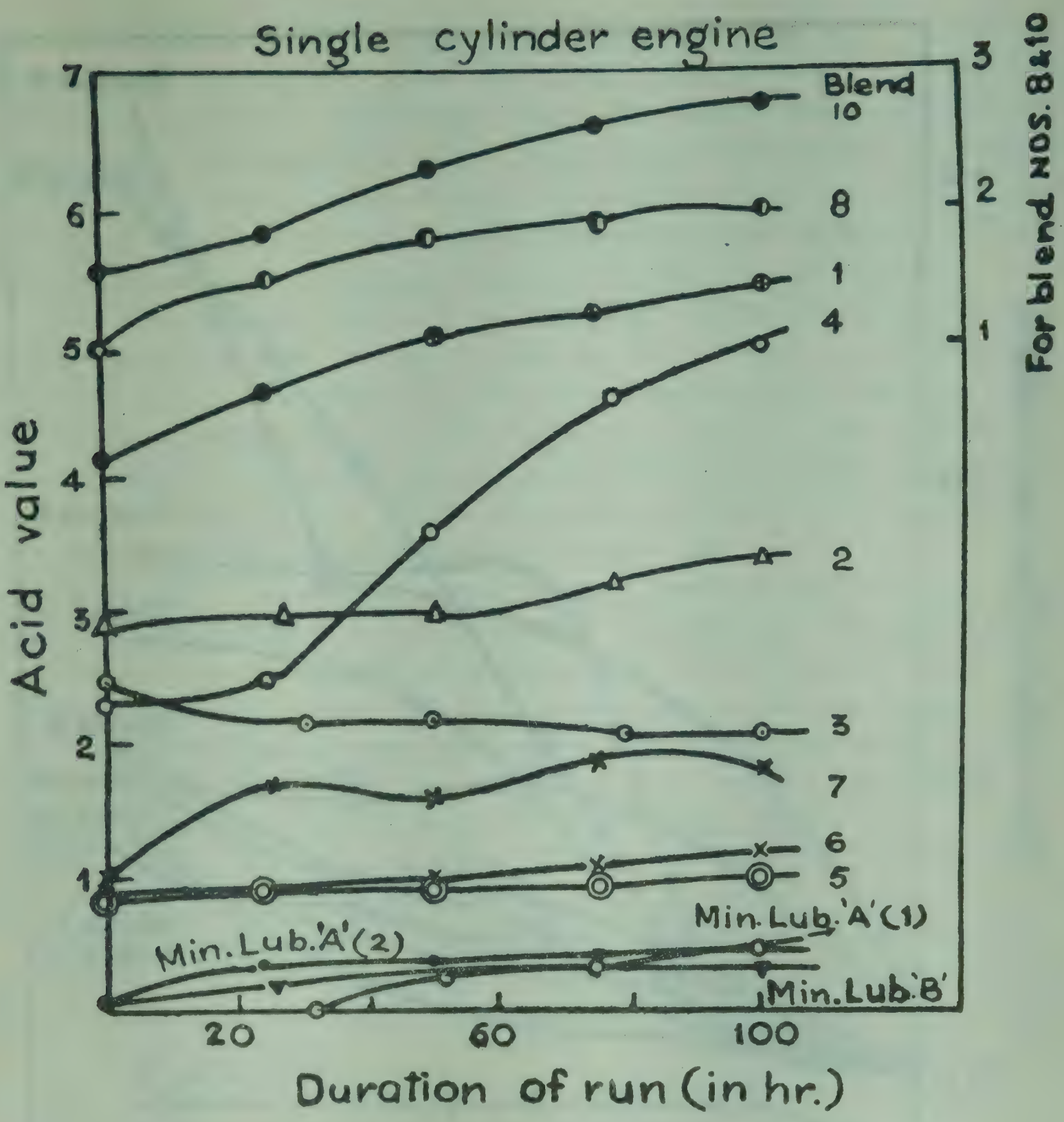


Fig. 5—Change of acid value with duration of run (Lister Set)

is, therefore, the fact that the degree of saturation of the blends increased with the length of operation and reached a maximum value before approximately 80 hrs. operation.

The ash content (Fig. 10) of all the blends as well as of the mineral lubricants showed an increase with the length of operation. The ash content is due primarily to the dust or other impurities finding their way along with the introduced air and also to the introduction of metallic impurities from the various engine parts as a result of wear. In view of the fact that the particular engine in which the investigation was carried out was not provided with an air filter, and as the experiments were carried out under varying weather conditions prevailing during the different parts of the year, the amount of dust and other impurities finding their way inside the engine naturally varied from blend to blend. The figures for ash or iron content

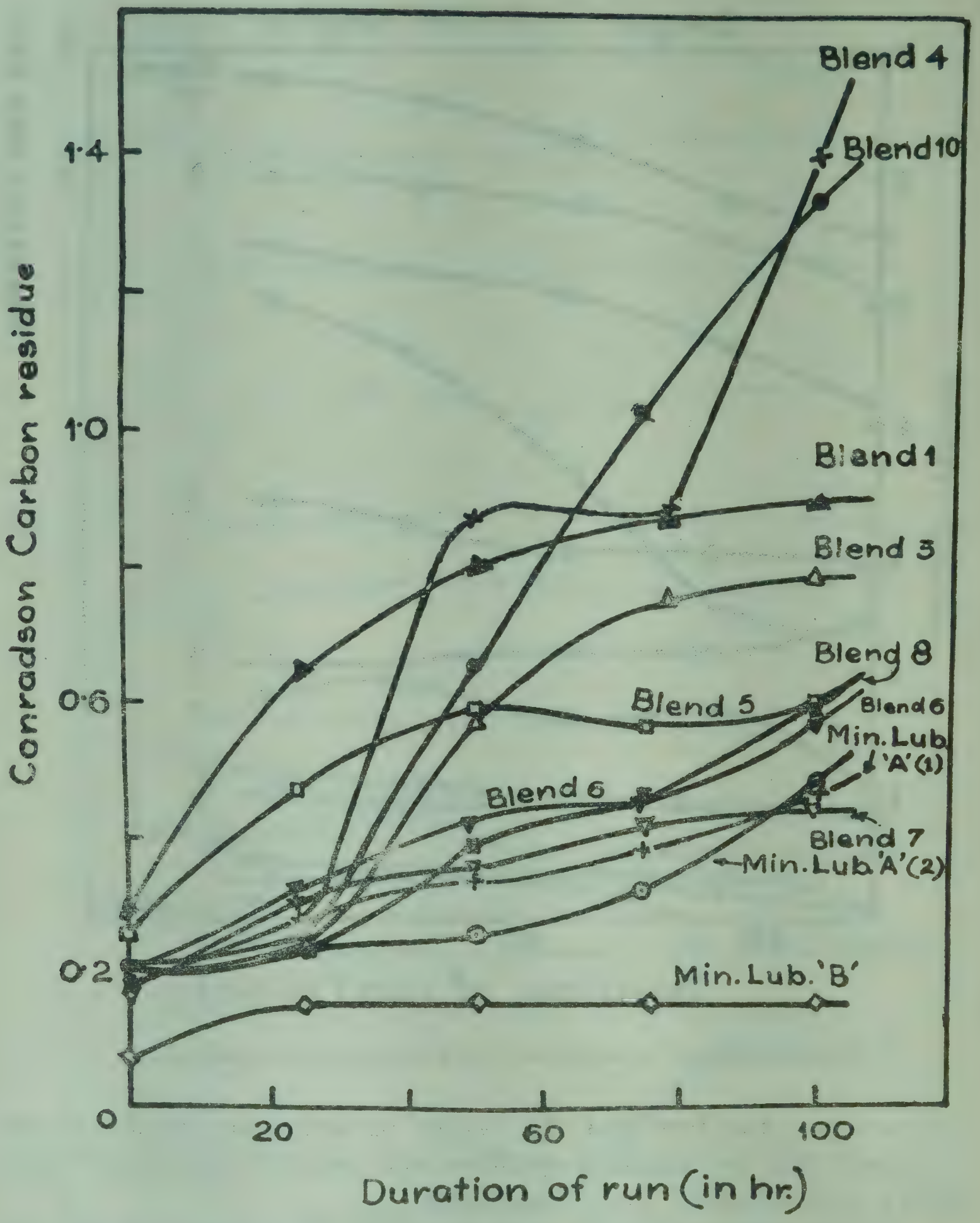


Fig. 6—Change of Conradson carbon residue with duration of run (Lister Set)

(Fig. 11) of the oil, therefore, furnished no definite criterion of the relative degree of wear as a result of engine operation and should not be taken as anything but a rough indication of the degree of wear experienced by the metallic parts of the engine.

From Table 6 and Fig. 12 it is clear that the maximum equilibrium temperatures of the crank case oil in the case of runs with Blends 3 (α-Napthol blend), 7 and 8 (α-Napthylamine blends) were practically of the same order, but somewhat less than that obtained with

reference lubricant "A", while those obtained with the remaining blends were nearly the same as in the case of the run with the reference lubricant. Assuming that the crank case equilibrium temperature is independent of the room temperature and is a function of frictional losses under similar operating conditions, it may be concluded that the frictional characteristics of the vegetable oils are practically as good as those of the mineral oils, if not superior.

The consumption of petrol per B.h.p. hr. (Table 6) should also be proportional to the frictional loss if the output is maintained constant and it was found that the consumption in the case of runs of all the blends except the two mineral-vegetable ones is more or less similar to that obtained in the standardization runs. However, there does not exist a strict correlation between the equilibrium temperature and the consumption in every case.

With regard to cylinder wear, it may be observed that, with the exception of Blends 2, 3 and 8, all the vegetable oil blends behaved as satisfactorily as the reference lubricants, but the loss of weight of the top piston ring, which has been generally accepted as an index of wear, failed to establish any correlation with the cylinder wear figures. However, among the pure vegetable oil blends, Blends 3, 4 and 7 behaved best and showed a loss of weight which was approximately 25 per cent higher than that in the case of the reference lubricant (second standardization run).

Regarding the removal of iron (Fig. 15) Blend 7 proved superior to all others, giving an iron content figure of 0.149 g. as against 0.101 g. for the reference lubricant. The other two blends which gave the next

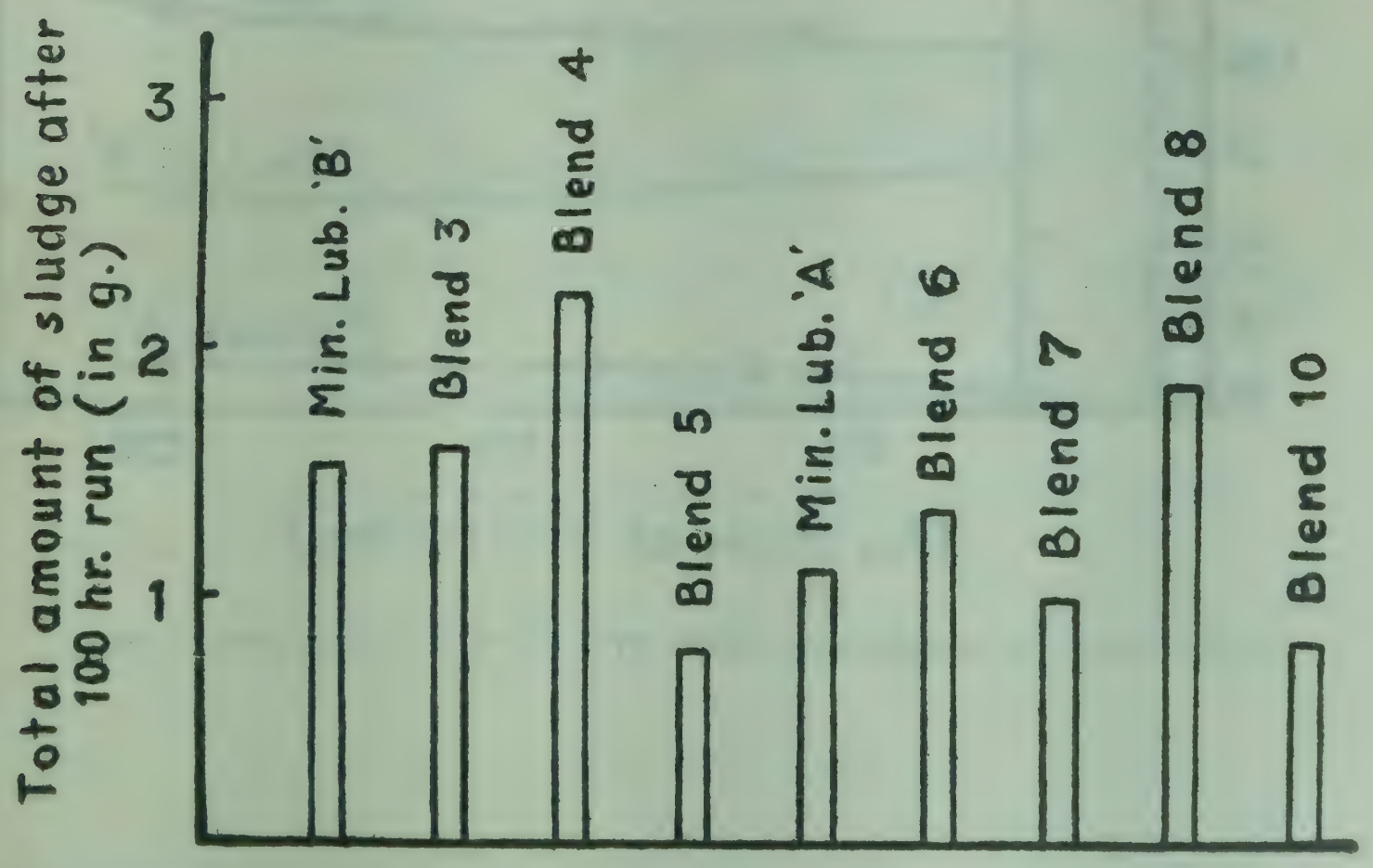


Fig. 7—Graphical representation of the amount of sludge in crank case oil obtained with different blends as a result of 100 hrs. run (Lister Set)

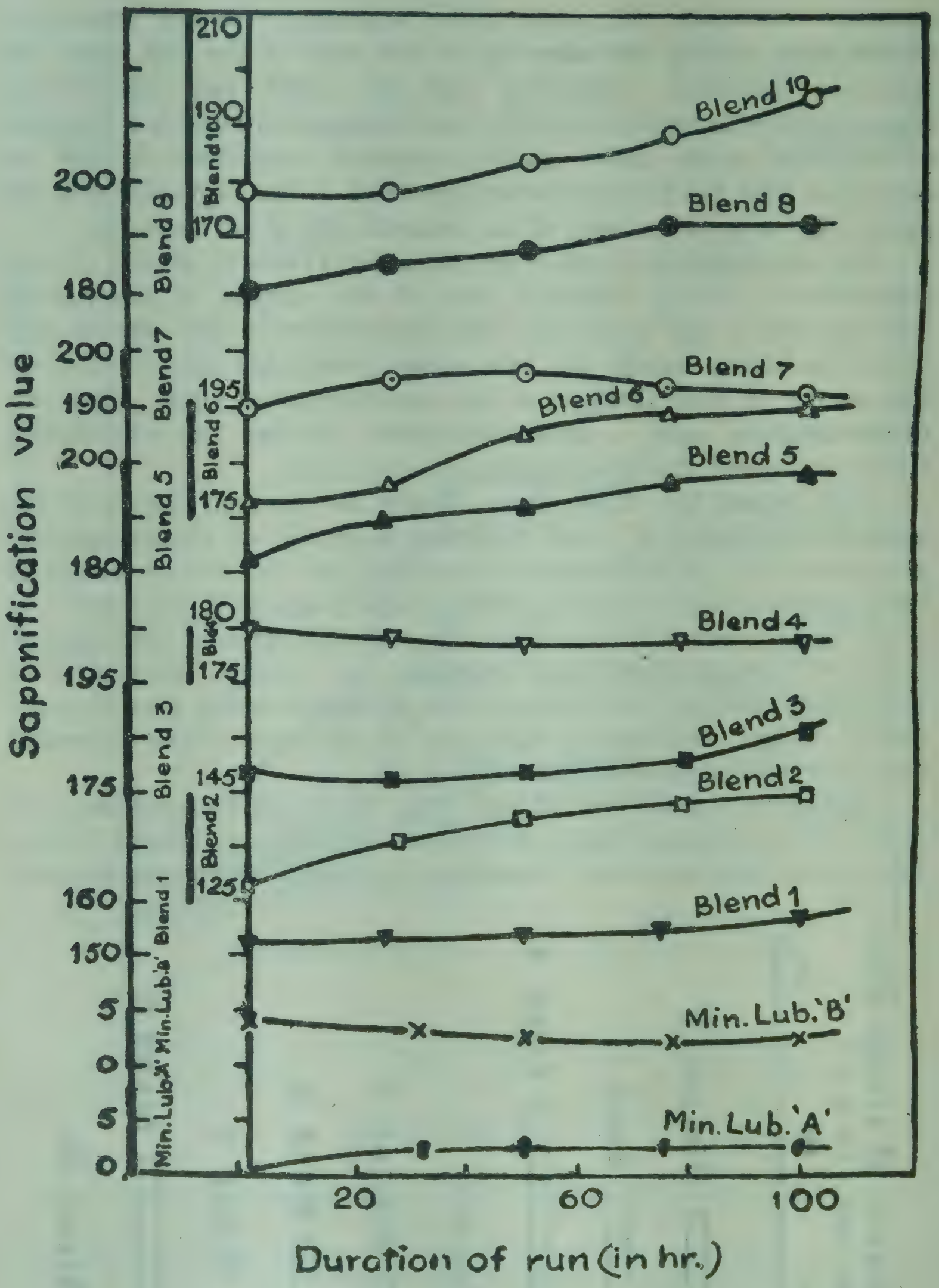


Fig. 8—Change in saponification value with duration of run (Lister Set)

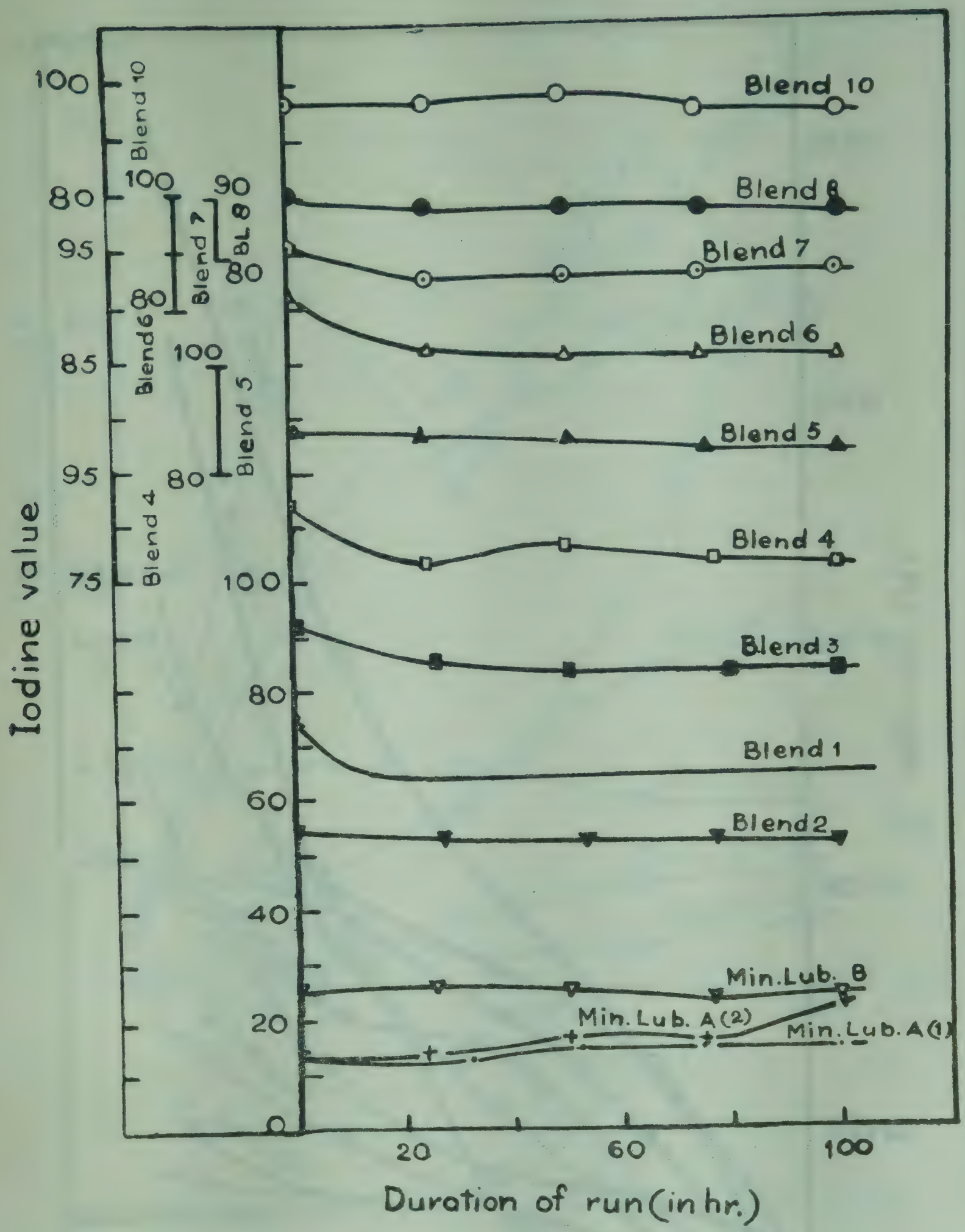


Fig. 9—Change in iodine value with duration of run (Lister Set)

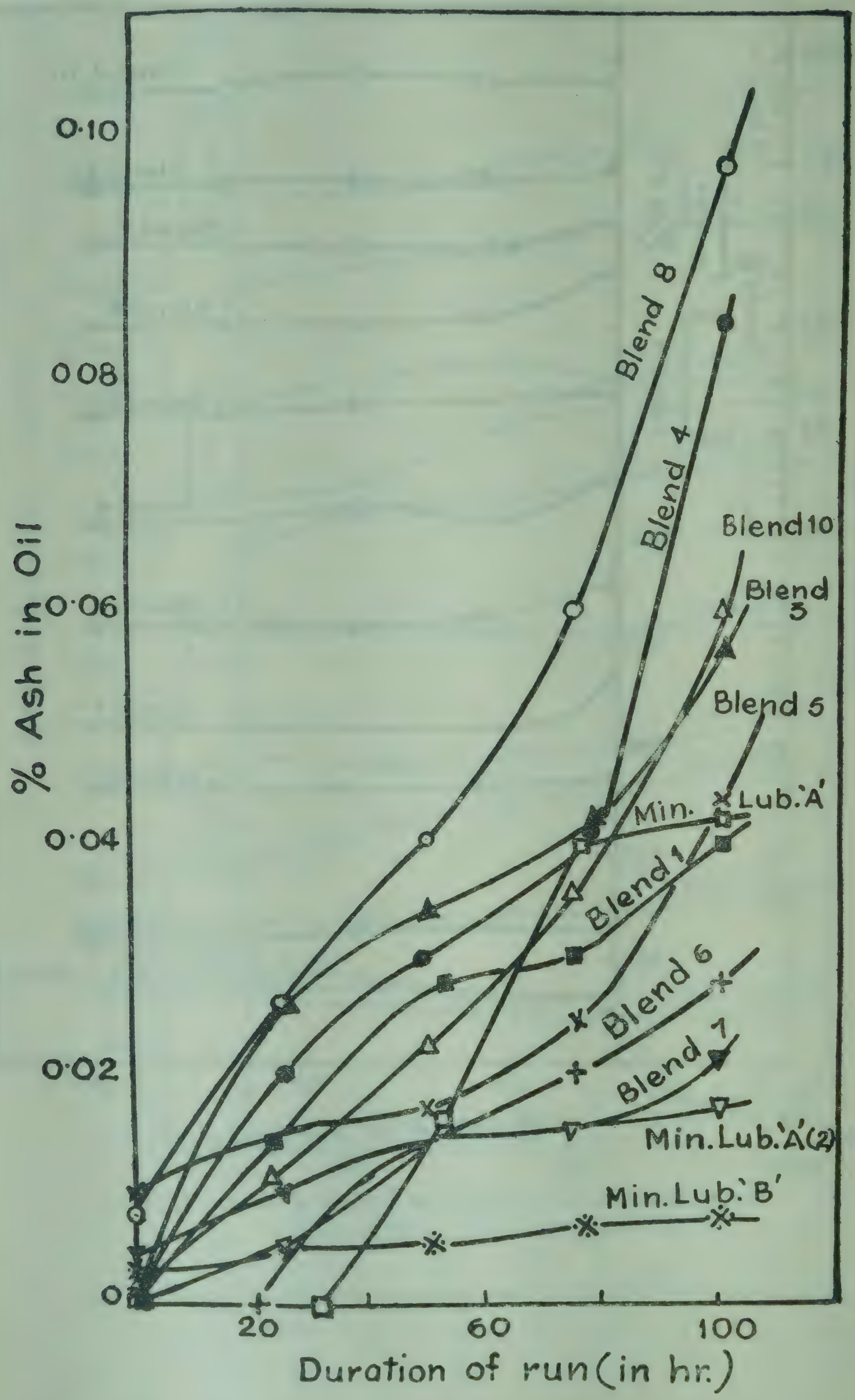


Fig. 10—Change in ash content with duration of run (Lister Set)

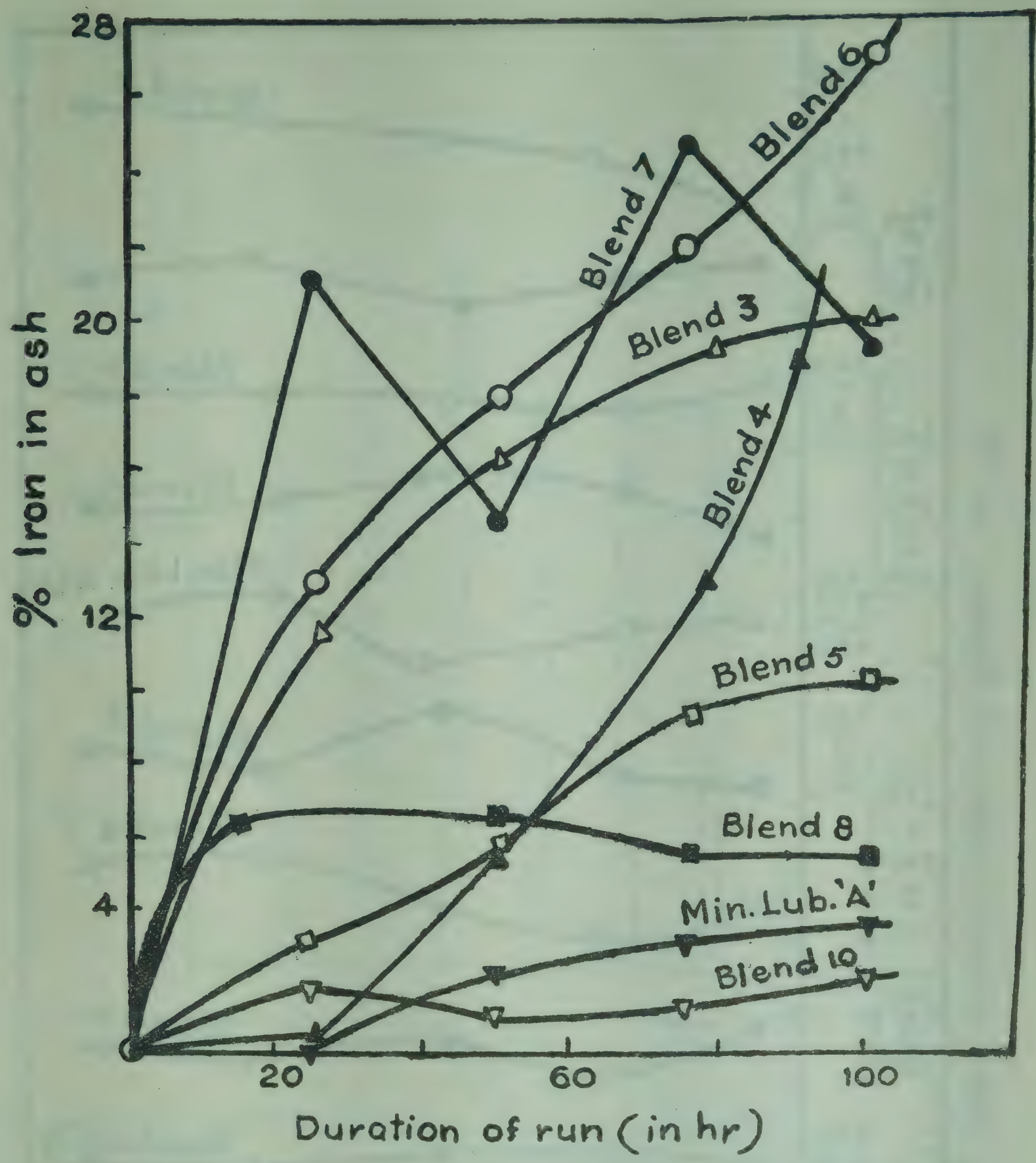


Fig. 11—Change in iron content in ash with duration of run (Lister Set)

best results are Blends 5 and 6, which gave iron content figures of 0.195 g. and 0.226 g. respectively.

It is clear from the results given in Table 7 and Fig. 16 that the nature of deposit on the piston top and cylinder head with practically all the blends was of the same type as that obtained with mineral reference lubricant "A", although the amount varied from blend to blend. The amount of deposit on the underside of the piston with reference lubricant "A" was practically nil as against variable amounts (0.34 to 2.5 g.) in the case of the stabilized vegetable oil blends. The total amount of deposit on the piston top and cylinder head, including that on the underside, obtained with Blends 7 and 8,

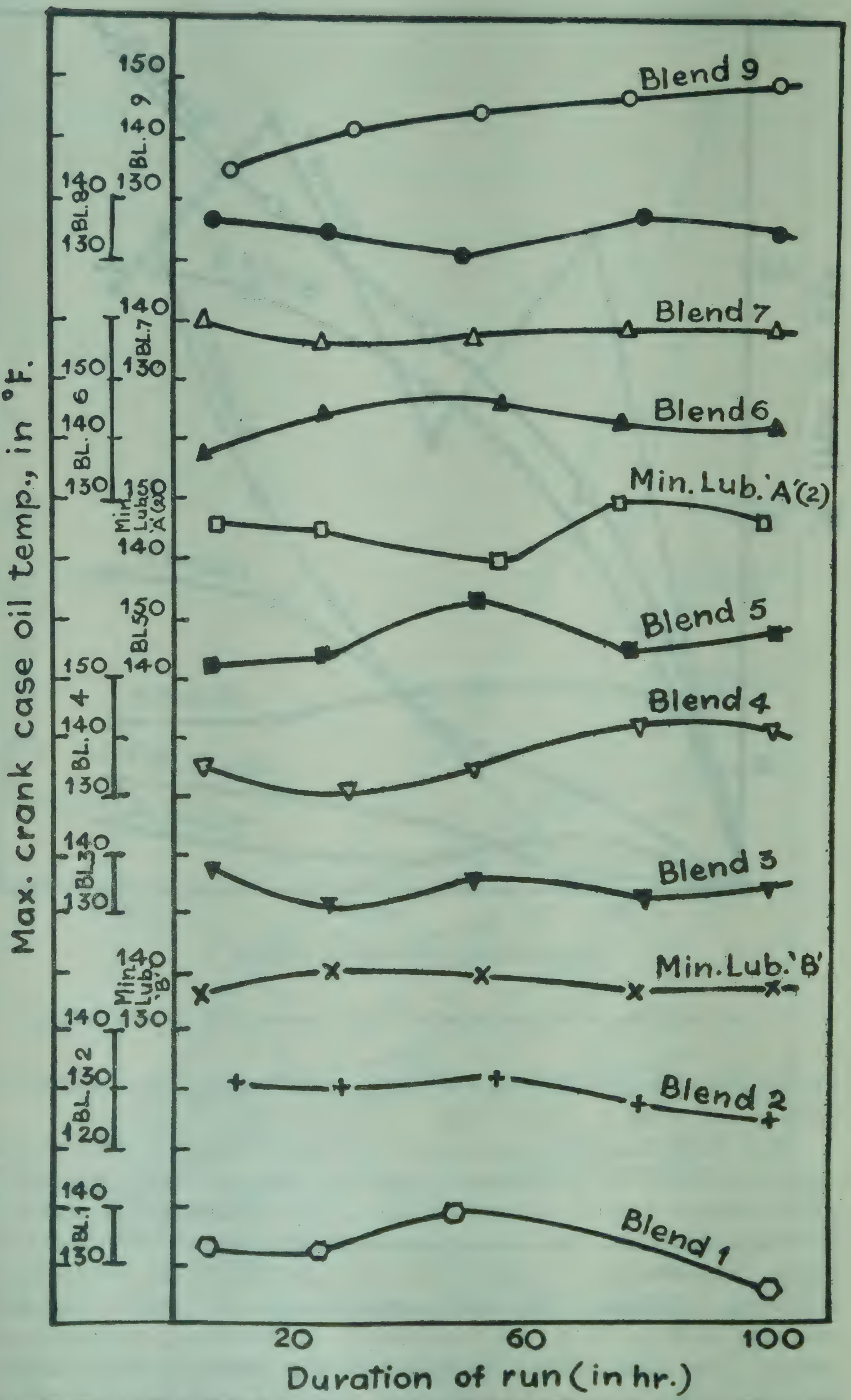


Fig. 12—Change in maximum crank case oil temperature with duration of run (Lister Set)

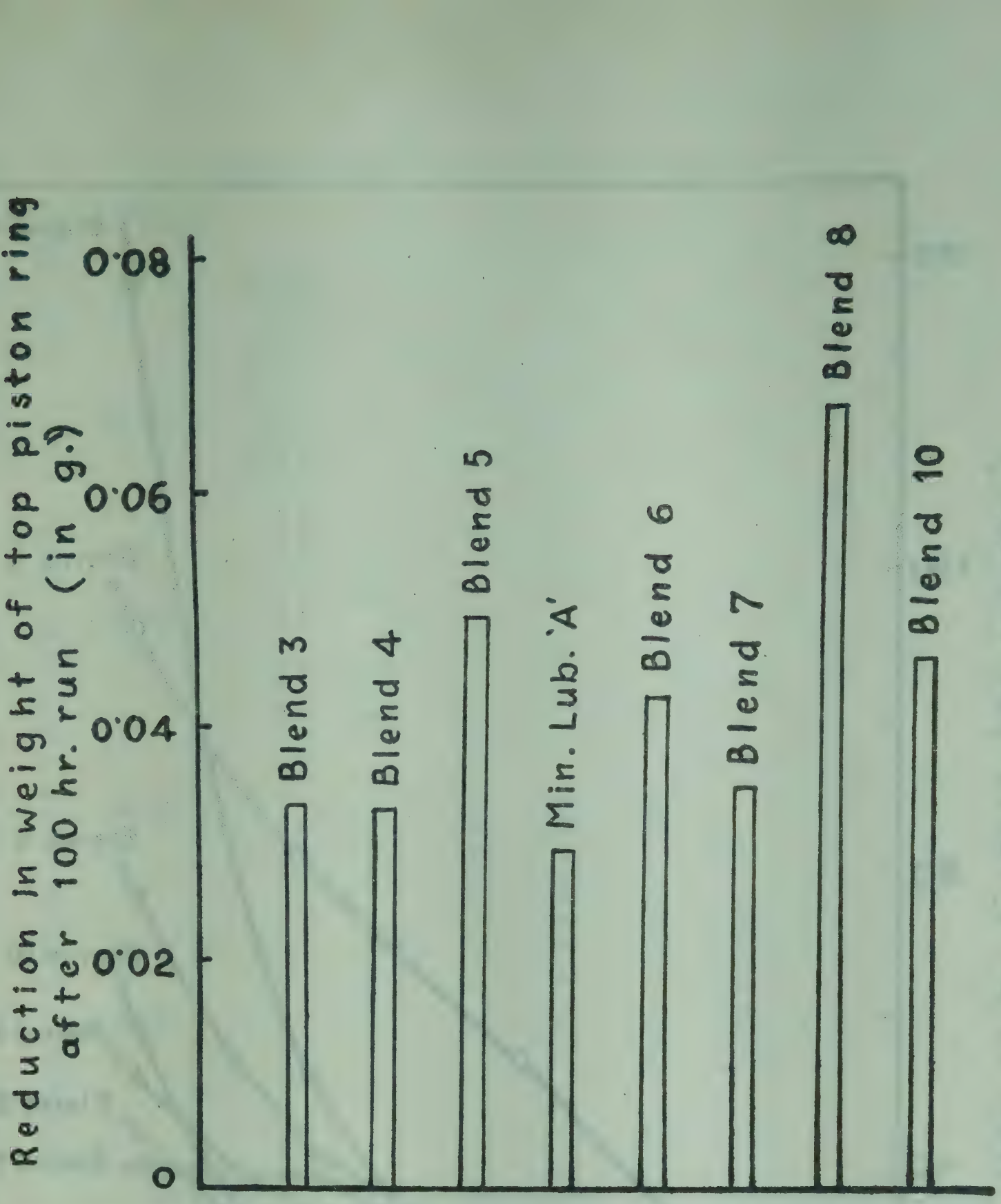


Fig. 13—Graphical representation of the loss in weight of top piston ring after 100 hrs. run (Lister Set)

was definitely less than that with the first standardization run with reference lubricant "A" and quite comparable with that obtained with the second standardization run with the same reference lubricant. Also the deposit on all these parts obtained with Blend 4 (the untreated blend) weighed as much as 16.5 g., whereas that obtained with Blends 7 and 8 weighed only 1.82 and 1.32 g. respectively, clearly demonstrating the very remarkable improvement in this effect caused by the addition of stabilizers.

The nature of deposits on the ring lands and grooves, with all the Blends except 4 and 5, was similar to that produced by the reference lubricant "A". The deposit obtained with Blend 4 (the untreated castor and groundnut oil mixture) was of a distinctly gummy character and caused the clogging of a large number of scraper ring slots and the sticking of the top piston ring. The deposit produced by Blend 5 was somewhat gummy in the region of top ring

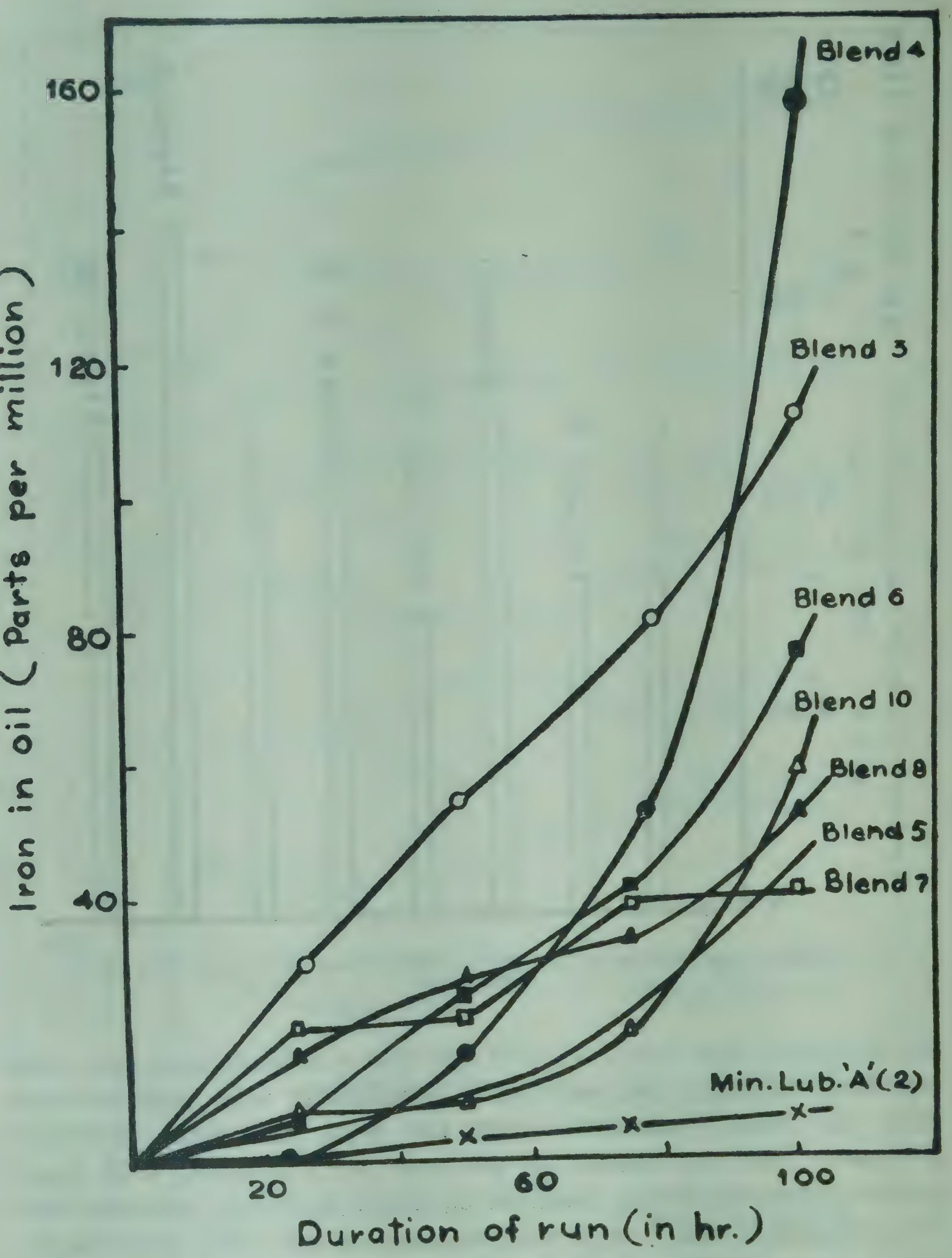


Fig. 14—Change in iron content (soluble iron) of oil with duration of run (Lister Set)

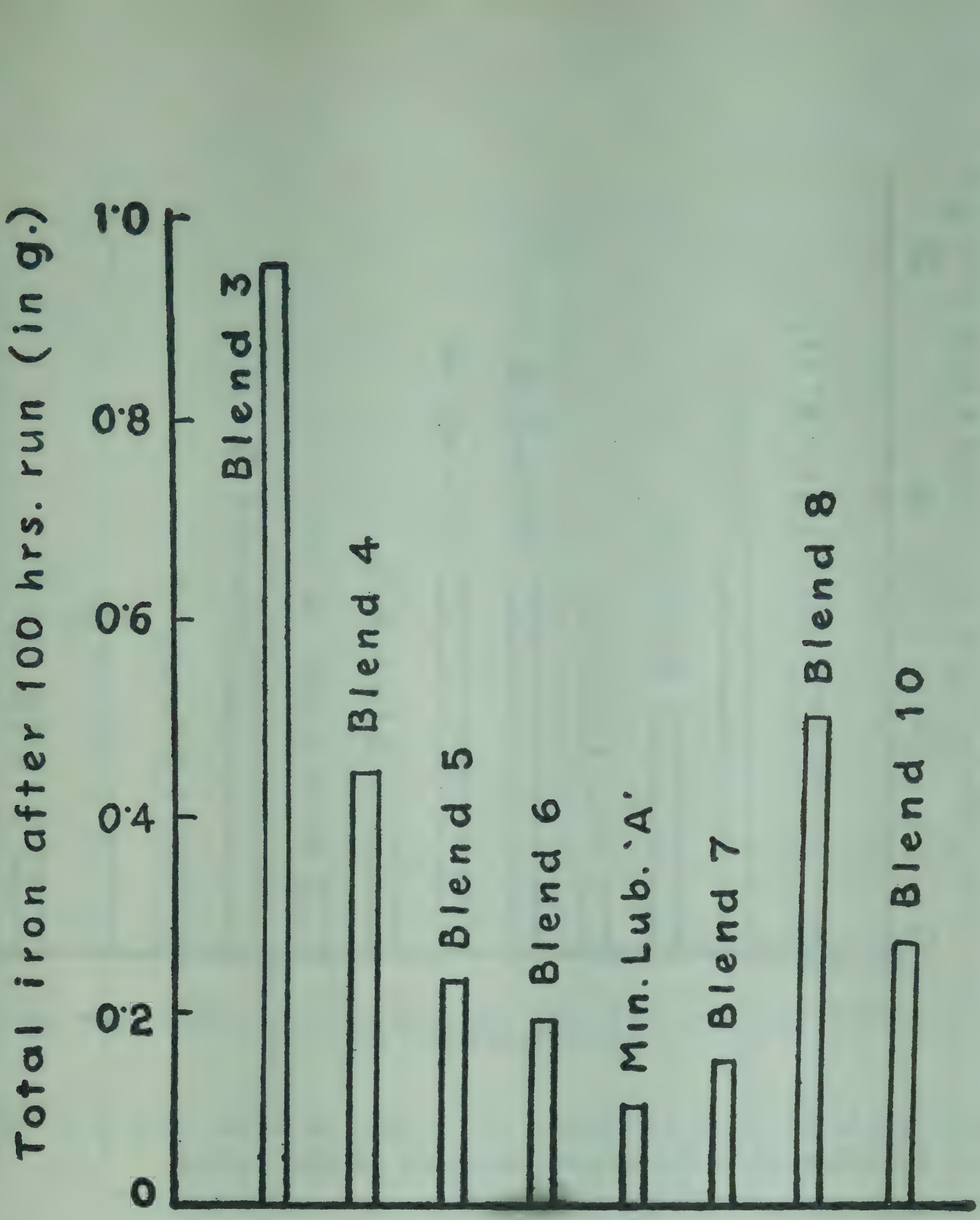


Fig. 15—Graphical representation of the total iron content (iron in solution and iron in sludge) in crank case oil after 100 hr. run (Lister Set)

groove and also caused the sticking of the top ring. On the other hand, Blend 6 which is exactly identical in composition with Blend 5, except for the fact that its soap content was slightly lower, was quite free from these defects. It is, however, difficult to say at this stage whether the ring sticking was due to excess of soap or whether it was purely accidental. With the untreated oil, on the other hand, the deposits were definitely gummy in character not only on the top ring groove but also in the other ring grooves showing undoubtedly the effect of stabilizers on the treated blends.

With regard to the deposits on the valves, Table 7 indicates that the exhaust valves were singularly free from any deposit not only in the case of all the vegetable oil blends but also with the mineral reference lubricant "A", while the inlet valves in each case showed some amount of deposit, the nature and extent of which varied

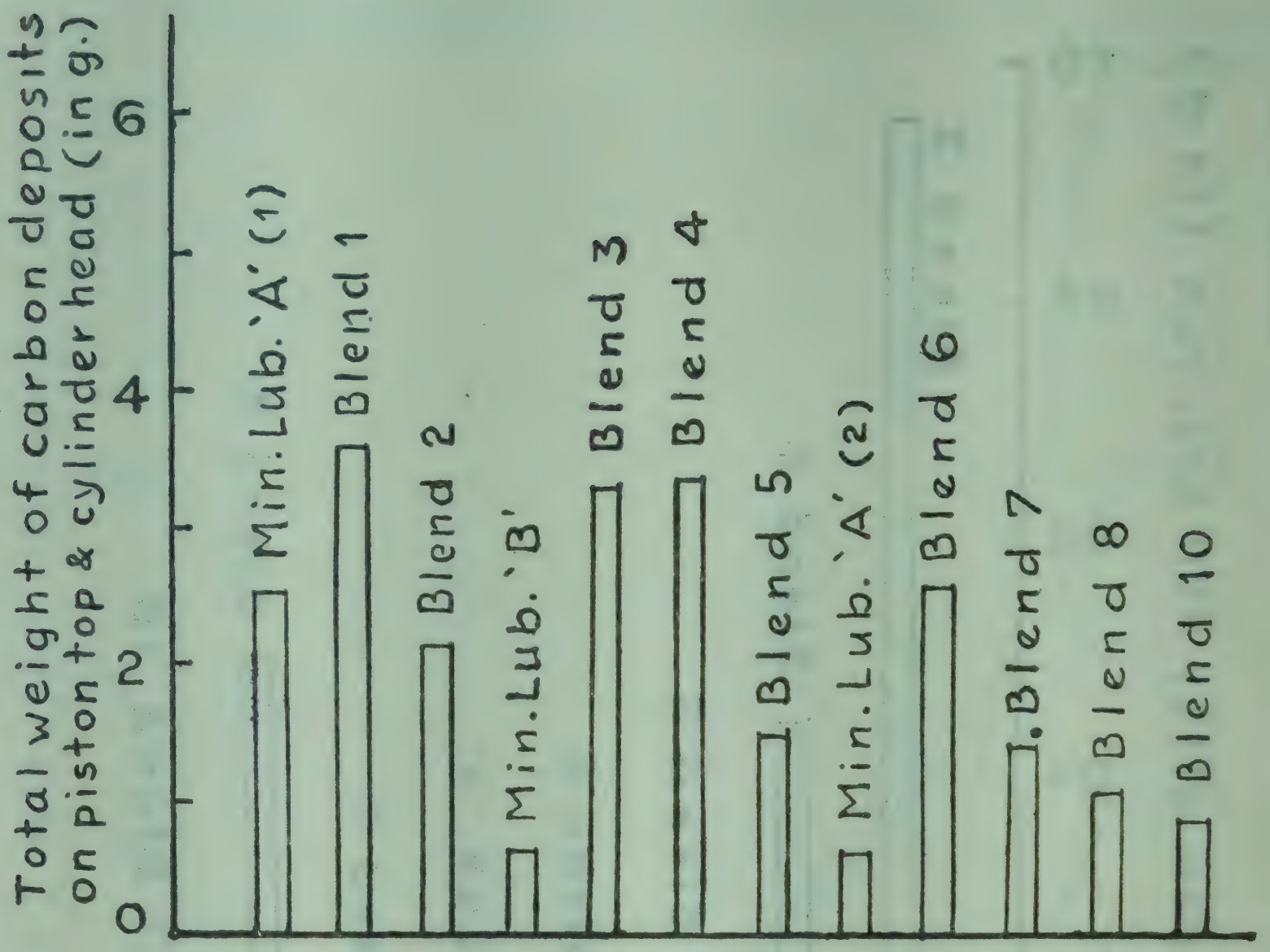


Fig. 16—Graphical representation of total amount of carbon deposit on piston top and cylinder head (Lister Set)

somewhat from blend to blend. In no case, however, was it so high as to interfere with the proper working of the valves.

Final Engine Tests

From the results of preliminary engine tests on the various blends, Blend 7, which is a castor and groundnut oil mixture with α-naphthylamine, proved superior to all others as regards general stability and wear characteristics. This blend was, therefore, subjected to more severe operating conditions in the larger engine (Morris).

While the engine test on this blend was in progress, a series of Air Ministry Oxidation Tests (modified), undertaken on rape oil in conjunction with different stabilizers, had practically reached the final stage, and it was found that α-naphthylamine, which proved quite satisfactory for the groundnut-castor oil blend, also proved to be quite a good stabilizer for rape oil. A 50-50 mixture of castor and rape seed oils with 1% α-naphthylamine (Blend 9) was, therefore, prepared for test in the larger unit. The resulting viscosity of the blend was 109 centistokes at 100°F. as compared with 128.6 centistokes in the case of Blend 7 and 122.1 centistokes in the case of reference

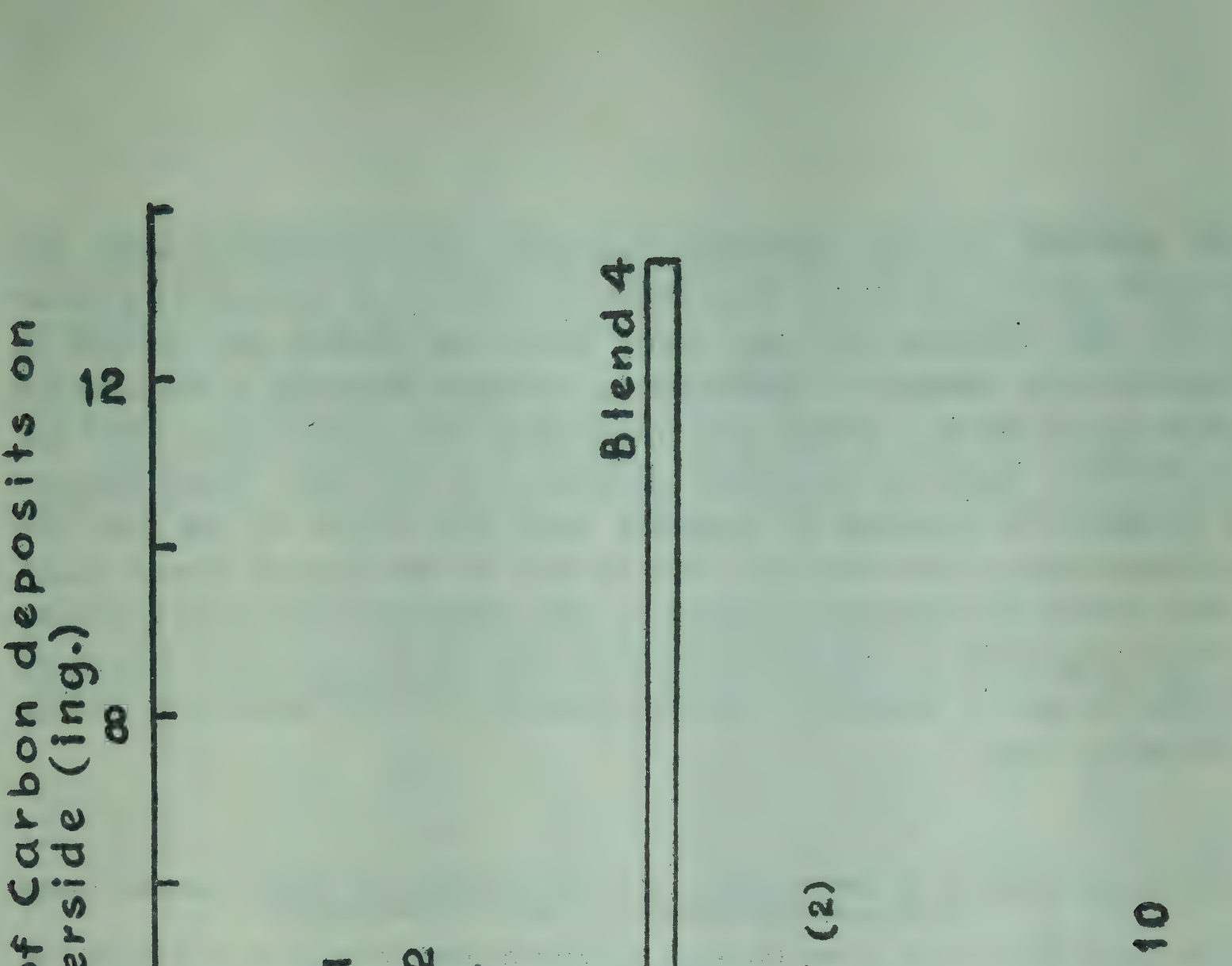


Fig. 17—Graphical representation of total amount of carbon deposit on piston underside (Lister Set)

lubricant "A". The lower initial viscosity of this blend was decided upon to see whether this would in any way influence the friction characteristics, which were found to be somewhat inferior in the case of Blend 7, when compared to reference lubricant "A".

The results of engine tests on these blends along with those on reference lubricant "A" are summarized in Tables 8, 9, 10 and 11.

Owing to undue vibration and leakage of oil through several auxiliary bearings of the Morris engine, while carrying out standardization runs, it was decided to carry out engine tests at 1,200 r.p.m. (instead of 1,500 r.p.m.) and at a correspondingly reduced load (10 B.h.p.).

A fresh standardization run was, therefore, carried out under the new conditions, and engine tests on Blends 7 and 9 were carried out under similar conditions.

The data presented in the Table 8 and Fig. 18 indicate that while

the viscosity of the reference lubricant "A" decreased with the progress of the run for the first 50 hrs., evidently on account of greater crank case dilution (3.0 per cent) occurring during this period, it subsequently showed a tendency to increase reaching a final value (42.8 c.s. at 140°F.), which was lower than the initial figure (43.7 c.s. at 140°F.). Both the vegetable oil blends, on the other hand, showed a tendency to increase in viscosity with the length of the run, the increase being most marked after 50 hrs. in the case of Blend 7 and after 75 hrs. in the case of Blend 9. The greater increase in viscosity of the vegetable oils as compared with that of the reference lubricant might be partly explained by the greater dilution occurring during the latter run.

TABLE 8—Changes in oil characteristics showing oxidation and thermal stability under engine operating conditions in 16 h.p. Morris engine

(The three figures given under any head correspond respectively to 0, 50 and 100 hrs. operation).

Blend	Viscosity at 140°F. c.s.	Rise in viscosity after 100 hrs. run %	Viscosity index	Acid value	Conradson carbon residue %	Sludge %	Total amount of sludge (in g.)	Oil consumption (% of total oil used)	Crank case dilution %
Mineral Lubricant "A" ..	43.7		102.0	0.06	0.19	..	..		..
	40.2		98.0	0.42	0.24	..	1.74	16.4	3.0
	42.8	—2.1	96.5	0.36	0.32	0.04	..		1.4
Blend 7	46.6		116.0	0.92	0.2	..	..		..
	47.7		116.5	1.55	0.37	..	..	15.8	1.2
	56.7	21.7	114.5	2.25	0.57	0.03	1.40		1.0
Blend 9	41.2		121.0	1.19	0.2	..	..		..
	42.7		121.0	2.0	0.23	..	..	17.8	1.0
	48.2	17.0	120.2	2.0	0.49	0.03	1.21	48.2	1.2

TABLE 9—Changes in oil characteristics other than those shown in Table 8 under engine operating conditions in the 16 h.p. Morris engine

(The three figures given under any head correspond respectively to 0, 50 and 100 hr. operation).

Blend	Specific gravity 100°F. at 100°F.	Saponification value	Iodine value	Ash %	Iron in ash %
Mineral lubricant "A" ..	0.8738	0.8	12.2	Nil	Nil
..	0.8758	1.4	12.9	0.013	11.8
	0.8769	4.7	12.2	0.014	20.3
Blend 7	0.9399	185.0	93.0	0.003	Nil
	0.9403	184.6	83.7	0.010	16.9
	0.9462	195.5	81.9	0.022	13.6
Blend 9	0.9333	180.3	96.0	0.005	Nil
	0.9343	189.2	96.0	0.012	10.4
	0.9379	190.0	93.0	0.018	7.4

As regards the acid value (Fig. 20), it will be seen that while it increased by 0.30 in the case of the reference lubricant "A", the corresponding increases in Blends 7 and 8 were 1.33 and 0.81 respectively. The Conradson carbon residue figures of both the vegetable oil blends were also slightly higher (Fig. 21).

Both the vegetable oil blends, however, developed appreciably less sludge than the reference lubricant (Fig. 22). The oil consump-

TABLE 10—Friction and wear characteristics of the oils as brought out by 100 hr. engine test in the 16 h.p. Morris engine

(The three figures given under any head correspond respectively to 0, 50 and 100 hr. operation).

Blend	Room temp. during the period of run (°F.)	Max. crank case oil temp. during the period of run (°F.)	Consumption of petrol per B.h.p. hr. (in lb.)	Cylinder wear at limiting position of top ring travel (in in.)*	Reduction in wt of top piston after 100 hr. run (in g.)*	Iron in crank case oil (parts per million)	Total iron content of crank case oil after 100 hrs. run (in g.)	Motoring losses (B.h.p.)
Mineral lubricant "A"	97—85	175—169	0.682	No measurable change in any cylinder	0.0110 0.0119 0.0145 0.0150	Nil 15.8 30.0	0.481	2.3 2.3 2.2
Blend 7	85—71	174—171	0.729	No measurable change 0.0002 0.0005	0.0288 0.0387 0.0177 0.0239	Nil 17.3 29.8	0.484	2.7 2.6 2.6
Blend 9	88—74	174—171	0.707	No measurable change 0.0003 No measurable change in remaining cylinders	0.0177 0.0109 0.0348 0.0103	Nil 12.1 14.1	0.273	2.6 2.3 2.6

* The four figures relate to cylinder Nos. 1 to 4 serially.

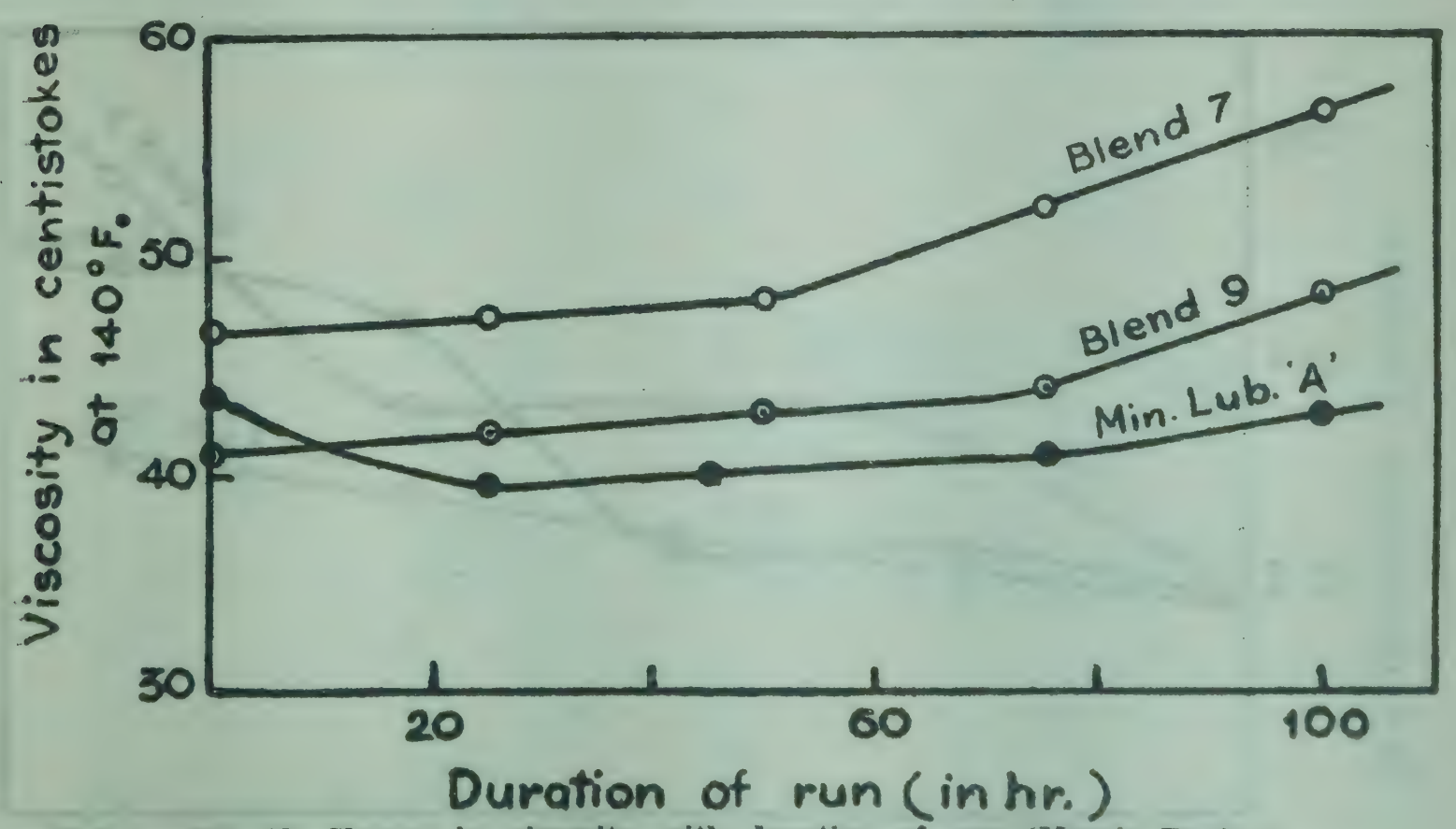


Fig. 18—Change in viscosity with duration of run (Morris Engine)

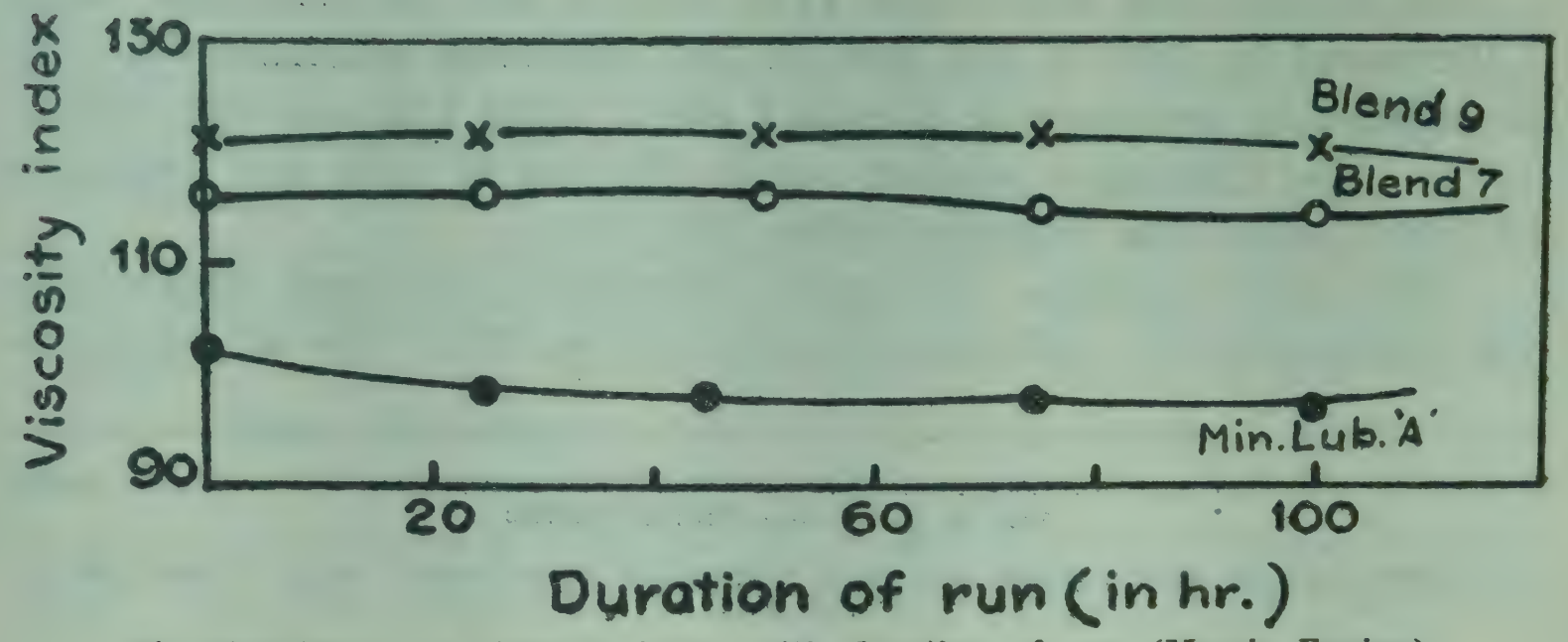


Fig. 19—Change in viscosity index with duration of run (Morris Engine)

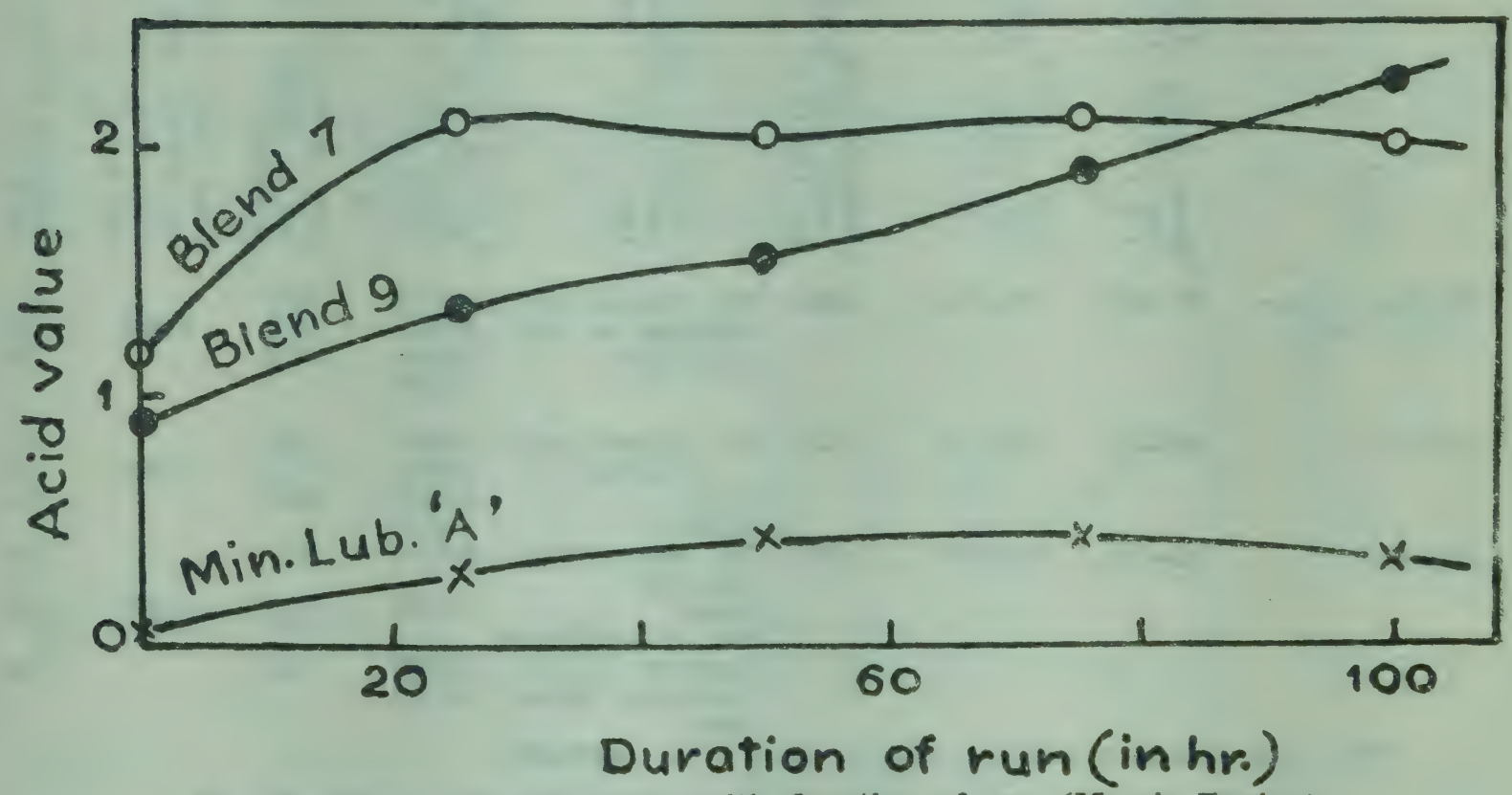


Fig. 20—Change in acid value with duration of run (Morris Engine)

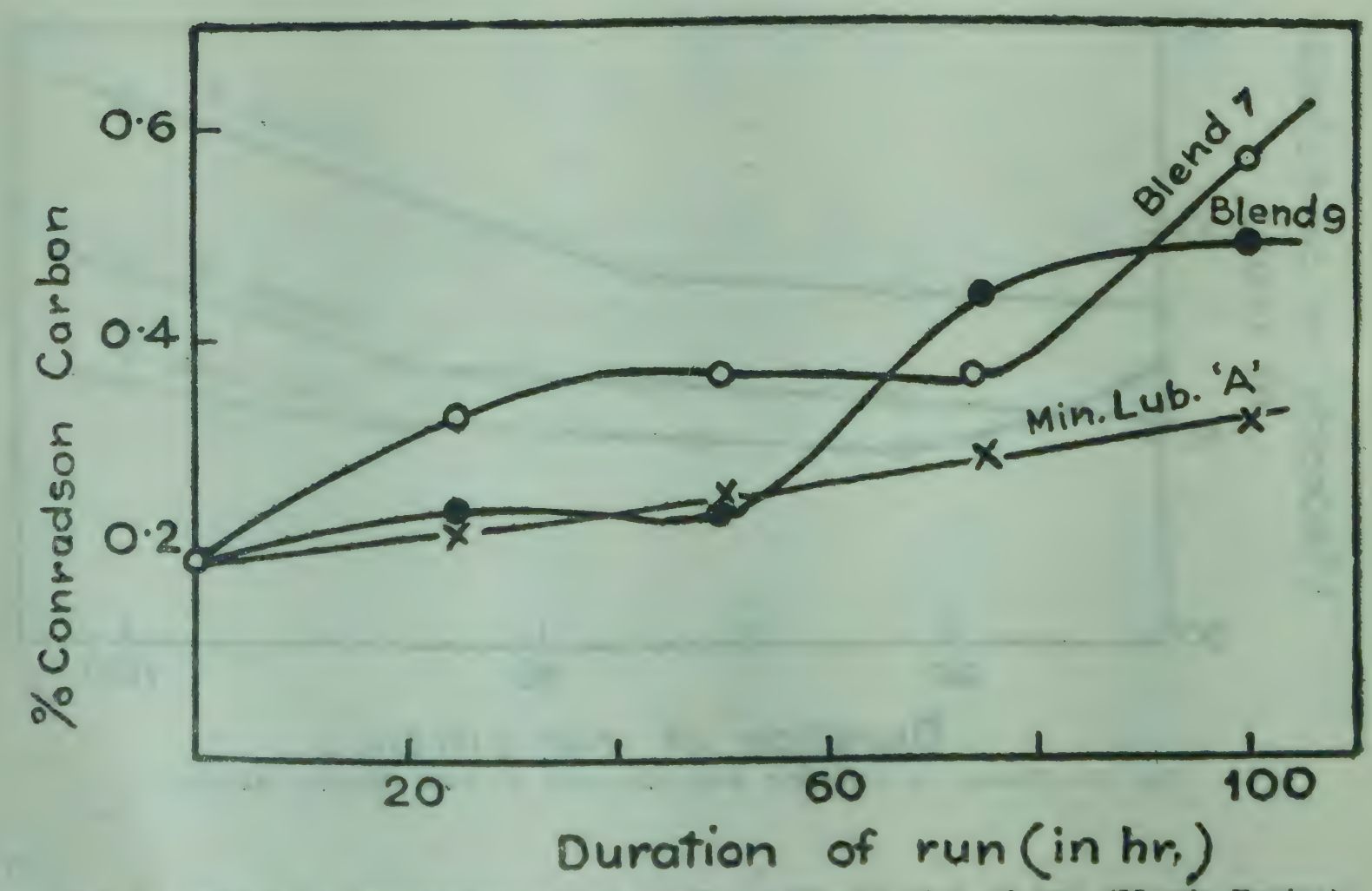


Fig. 21—Change in Conradson carbon residue with duration of run (Morris Engine)

TABLE 11—Nature and extent of deposits on engine parts after 100 hrs. run

(The four figures given under any head refer to the different cylinders).

Blend	Piston top and underside	Cylinder head	wt. (g.) Piston top	wt. (g.) Cylinder head	wt. (g.) Piston side underside	Ring, lands, grooves and skirt	Valves and valve pockets	Remarks
Mineral lubricant "A"	Top, in each case, showed thin, uniform, hard deposit removable with difficulty; underside lacquered brown	Thin, hard	0.517 0.536 0.530 0.482 2.065	0.900 1.220 2.439 1.971 6.530	Nil	Top land, in each case, showed thin deposit at places. Other ring lands and grooves covered with thin uniform deposit. Skirt lacquered black mostly near the gudgeon pin bearing ends	Inlet valve of cylinder 1, 2 and 4 showed granulated deposits over portions of shoulders. That of cylinder 3 covered with deposit. Portions of stem and face of valves either stained or covered with thin deposit. Exhaust valves showed no deposit	Interior of cylinders clean and free from score marks and so also were the principal bearing parts. Partial clogging of some scraper ring slots. Piston rings free in grooves
Blend 7	Top, in each case, covered with thin, uniform, hard deposit removable with great difficulty; scrapings black to brownish, giving impression of partially carbonized oil; underside lacquered brown	do.	0.571 0.606 0.617 0.672 2.466	1.121 1.595 2.410 2.825 7.951	Practically nil	Except for the top land, which was partly bright and partly covered, ring lands and grooves were generally covered with thin uniform deposit. Skirt, in each case, showed brownish coloration at places	Shoulder and part of stem of inlet valves of cylinder 1 and 2 covered with thick spongy deposit of resinous character. Cylinder 3 and 4 showed same type of deposit but in less amount. Total weight of deposits was 6.14 g. Exhaust valves showed no deposit	Interior of cylinders clean and free from score marks; so also were the principal bearing parts. No clogging of scraper ring slots or drain holes. Piston rings free in grooves.
Blend 9	Top covered with hard deposit removable with difficulty; scrapings similar to those of Blend 7; underside lacquered brown	Fairly hard, smooth, uniform	0.850 0.883 1.173 1.179 4.085	1.229 1.675 5.360 5.231 13.495	do.	Deposits on ring grooves and skirt similar to those obtained with Blend 7	Shoulders of inlet valves and pockets covered with resinous deposits, amount decreasing with distance from oil spray located in valve chamber near inlet valve of cylinder 1. Wt. of deposits are 1.86, 1.73, 1.38, 0.58 g. Inlet valve faces covered with thin film or stained; exhaust valve pockets, shoulders and stems free from deposits	do.

tion figures for Blends 7 and 9 were 15.8 per cent and 17.8 per cent respectively as compared with 16.4 per cent in the case of the reference lubricant.

It is clear from Table 9 (Fig. 23) that the nature and extent of the changes suffered by both vegetable oil blends as regards saponification value as a result of 100 hrs. run in the larger 4-cylinder engine were similar to those obtained in the smaller single cylinder unit (Table 5). It appears, therefore, that the more severe operating conditions in the high power engine produced no more serious changes in the characteristics than the comparatively less severe conditions of the smaller engine. The same remarks are more or less applicable in respect of changes in the iodine value (Fig. 24) which decreased slightly with the progress of the run indicating that the degree of saturation of the blends tended to increase with the duration of operation.

As regards the percentage of ash (Fig. 25) and the iron content, the remarks made in the case of the runs in the smaller engine apply to this case also. But generally, the increase in the ash content of the crank case oil in the case of both blends was slightly more than in the case of the reference lubricant "A". On the other hand, the percentage of iron in ash (Fig. 26) obtained with the reference lubricant steadily increased with the progress of the run, reaching a

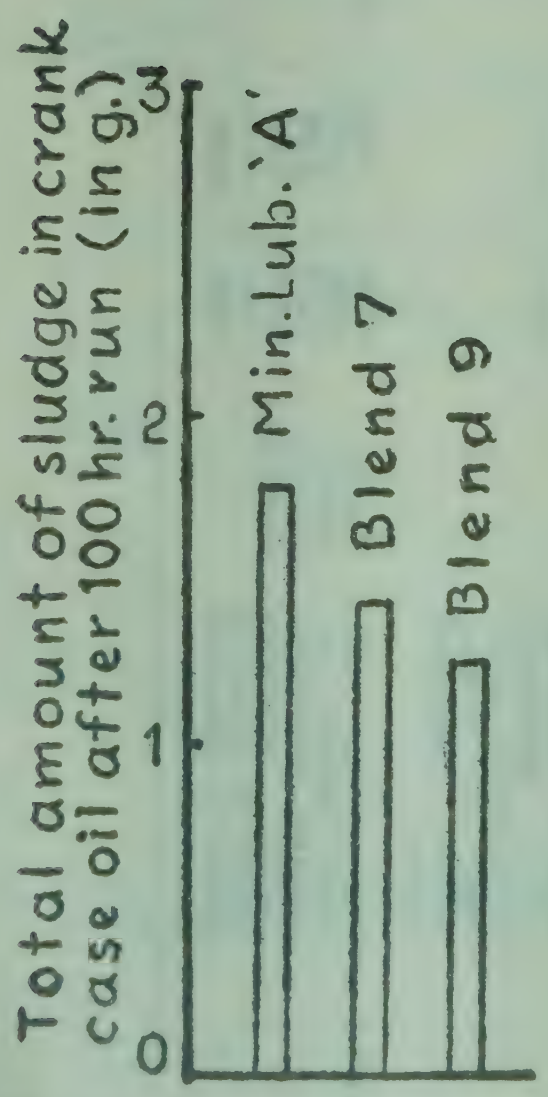


Fig. 22—Total sludge in crank case oil as a result of 100 hr. engine test (Morris Engine)

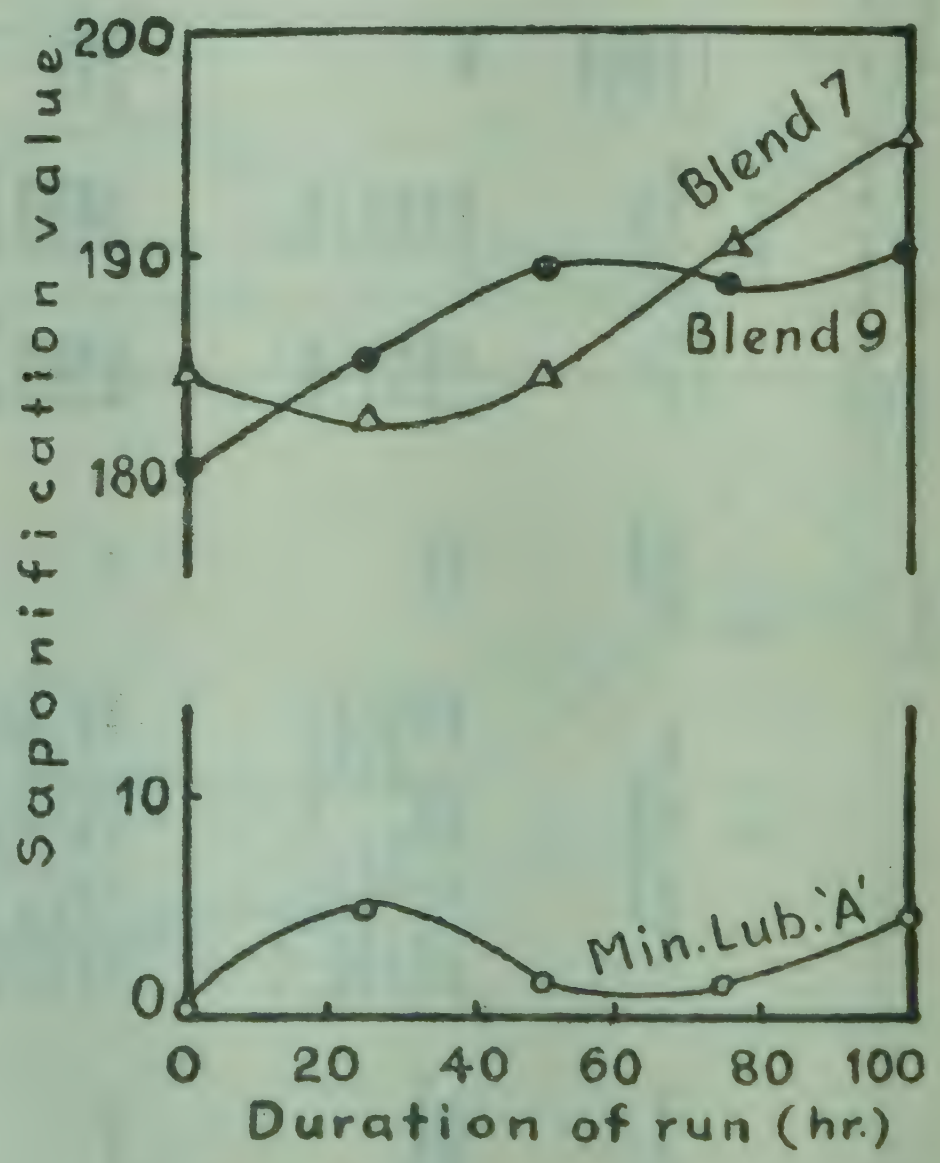


Fig. 23—Change in saponification value with duration of run (Morris Engine)

value of 20.3 per cent after 100 hrs. which was appreciably higher than the corresponding values in the case of both the vegetable oil blends. However, this value changed in a very irregular manner during the runs with both the blends.

A study of the results tabulated in Table 10 and shown graphically in Fig. 27 indicates that the equilibrium temperature of the crank case oil in the case of both the vegetable oil blends was practically identical and showed a fairly close agreement with that obtained with the mineral reference lubricant "A". The average room temperature, however, was slightly lower during the vegetable oil runs. The consumption of petrol per B.h.p. hr. with vegetable oil blends was 4-7 per cent higher than that obtained with the reference lubricant "A", although the frictional losses as determined by the motoring test were 10-16 per cent higher in the case of the blends. It appears, therefore, that there was lack of strict correlation between the frictional losses and the temperature rise of the crank case oil, but generally, the frictional characteristics of the vegetable oil blends on the whole were somewhat inferior to those of the reference lubricant.

With regard to wear on the basis of change in cylinder bore and the loss in weight of top piston ring, Blend 9 and reference lubricant "A" were practically similar (Fig. 28) except for the fact that the top ring of cylinder No. 3 after a run with the former blend showed a comparatively large reduction in weight and the bore of cylinder No. 1 showed a slightly greater increase in dimension. This appears to be accidental since it concerns one cylinder only.

The quantity of iron in solution in crank case oil at different stages of run (Fig. 29) with Blend 9 was appreciably lower than in the case of reference lubricant "A" while that obtained with Blend 7

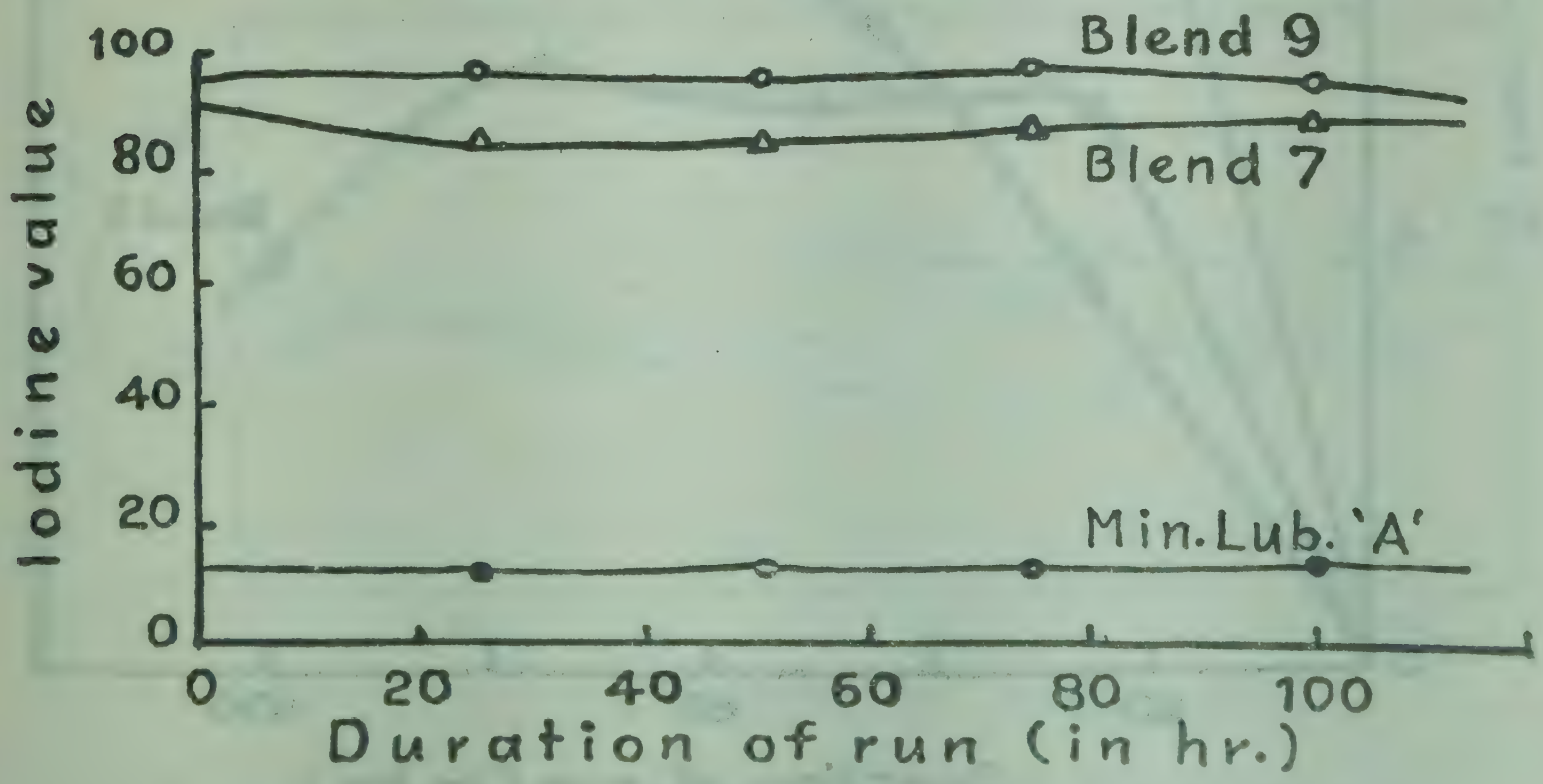


Fig. 24—Change in iodine value with duration of run (Morris Engine)

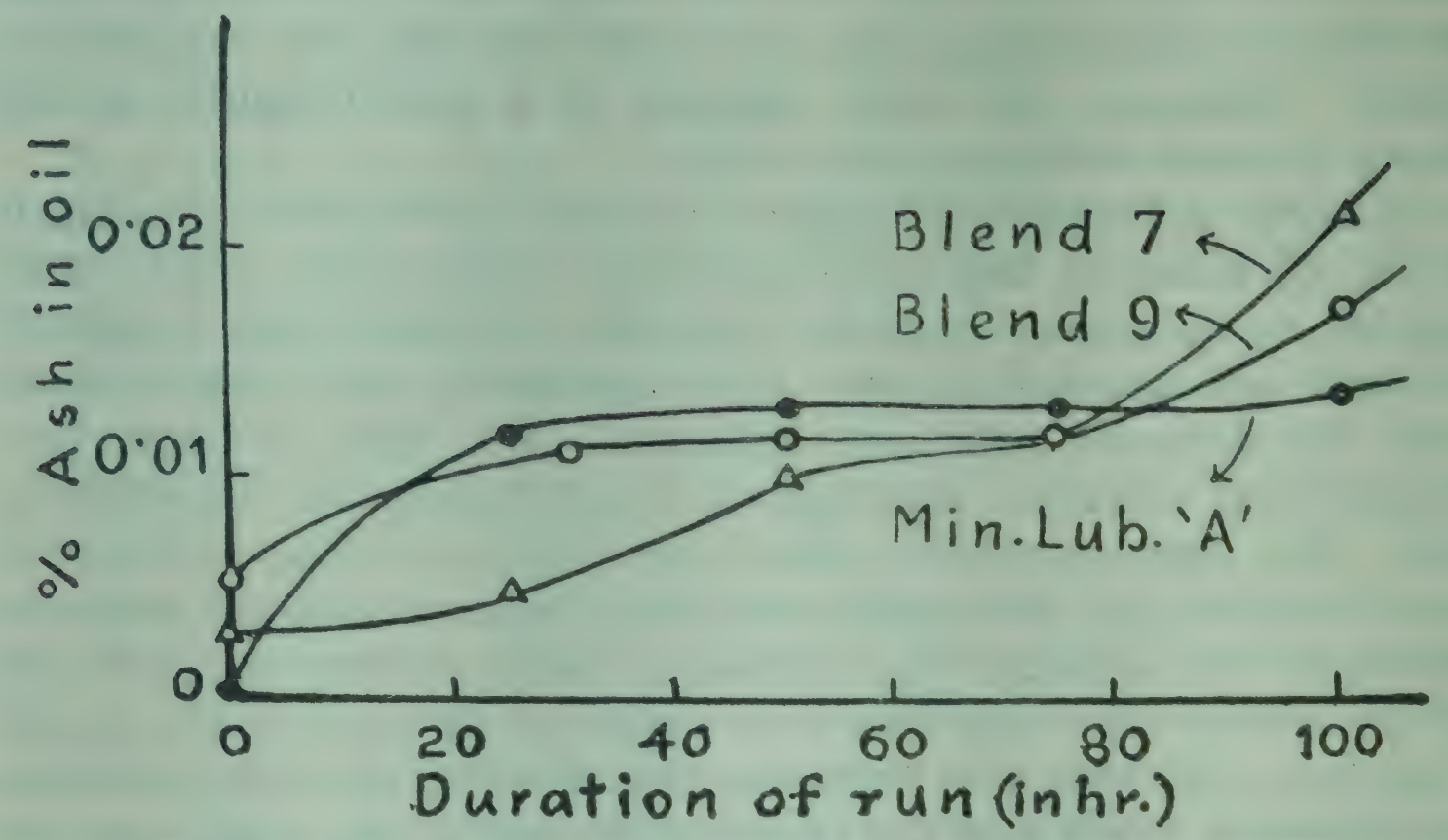


Fig. 25—Change in ash content with duration of run (Morris Engine)

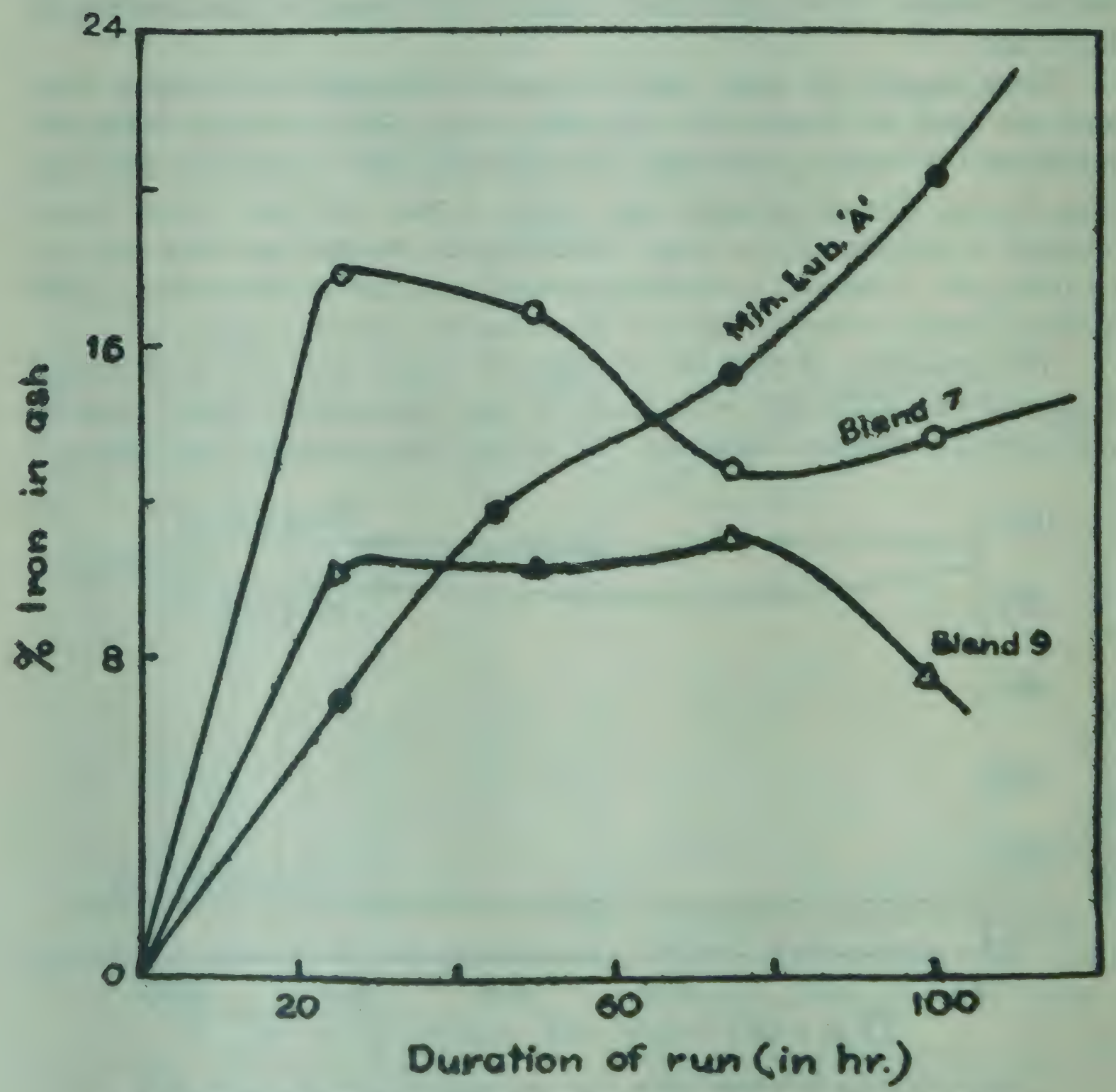


Fig. 26—Change in iron content of ash with duration of run (Morris Engine)

and reference lubricant "A" was practically identical. The total iron content of the crank case oil (including that of the sludge) (Fig. 30) at the end of 100 hrs. run with Blend 9 was also considerably lower than that obtained with run on Blend 7 or the reference lubricant "A", both of which gave similar performance in this respect.

A close examination of Table 11 brings out some interesting facts with regard to the nature and extent of deposits obtained with the vegetable oil blends, as compared with those obtained in the corresponding parts using the mineral lubricating oil "A". The most marked difference in behaviour between the two types of lubricants is in respect of the deposits observed on the piston top, cylinder head, inlet valves and valve pockets, while the nature and extent of deposits on the other parts, particularly the piston underside and the ring grooves, are, in general, identical in the case of both types of oils. The most outstanding fact that is brought out by the engine tests is that the two vegetable oil blends tried in the large unit (Morris) were at least free from the ring sticking tendency under high temperature conditions. It remains, however, to be seen whether the alternate high and low temperature running (or even continuous running), as encountered under certain service conditions are conducive to ring sticking.

With regard to weights of deposits on the piston top and cylinder head, the performance of Blend 7, is found to be slightly worse than that of mineral lubricant "A", but the performance of Blend 9 is definitely worse. Although Blend 7 is a castor and groundnut oil mixture and Blend 9 is a castor and rape oil mixture, the difference in behaviour cannot be wholly ascribed to the difference in composition or to the different carbonizing behaviour of the two

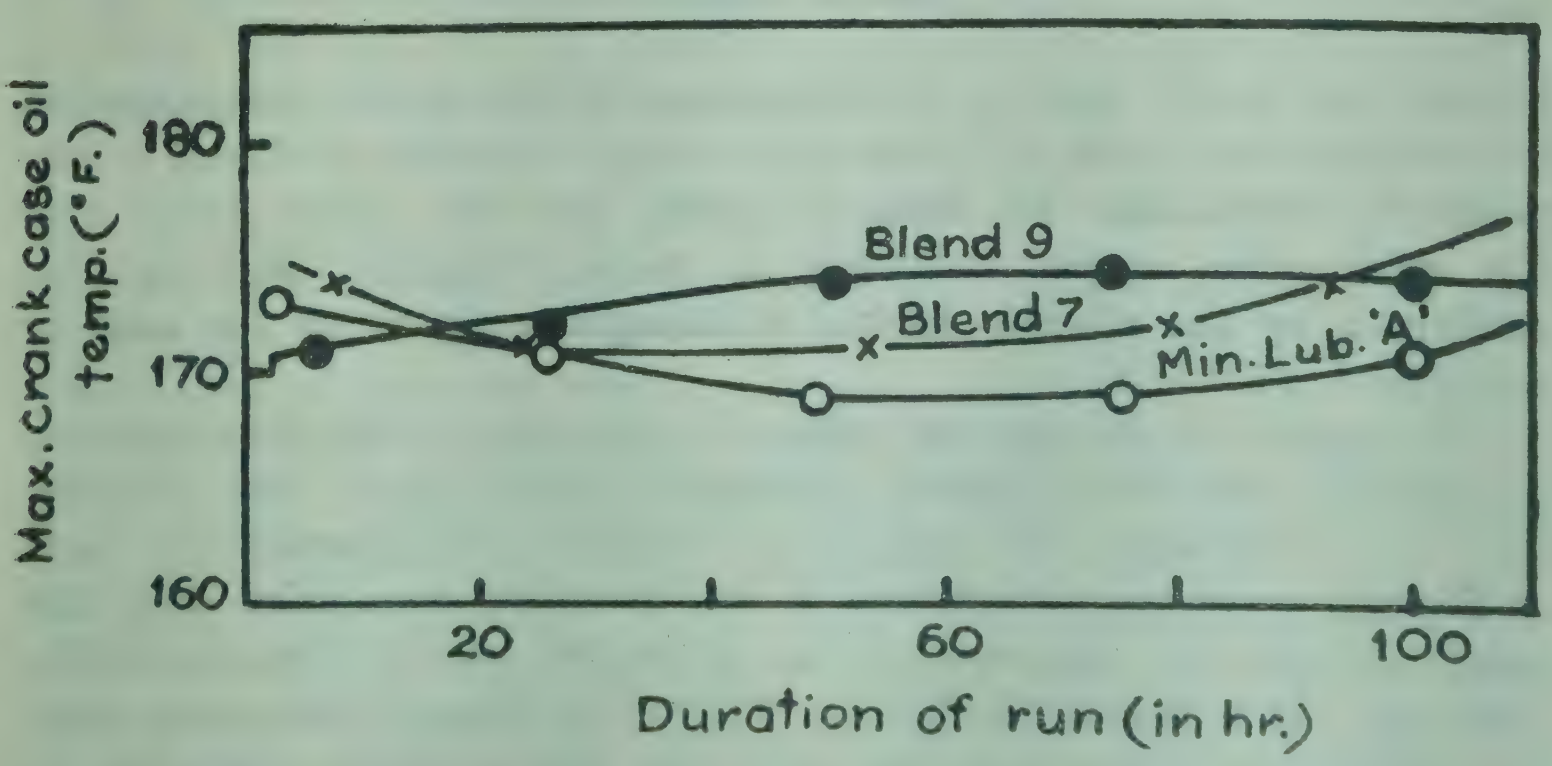


Fig. 27—Change in maximum crank case oil temperature with duration of run (Morris Engine)

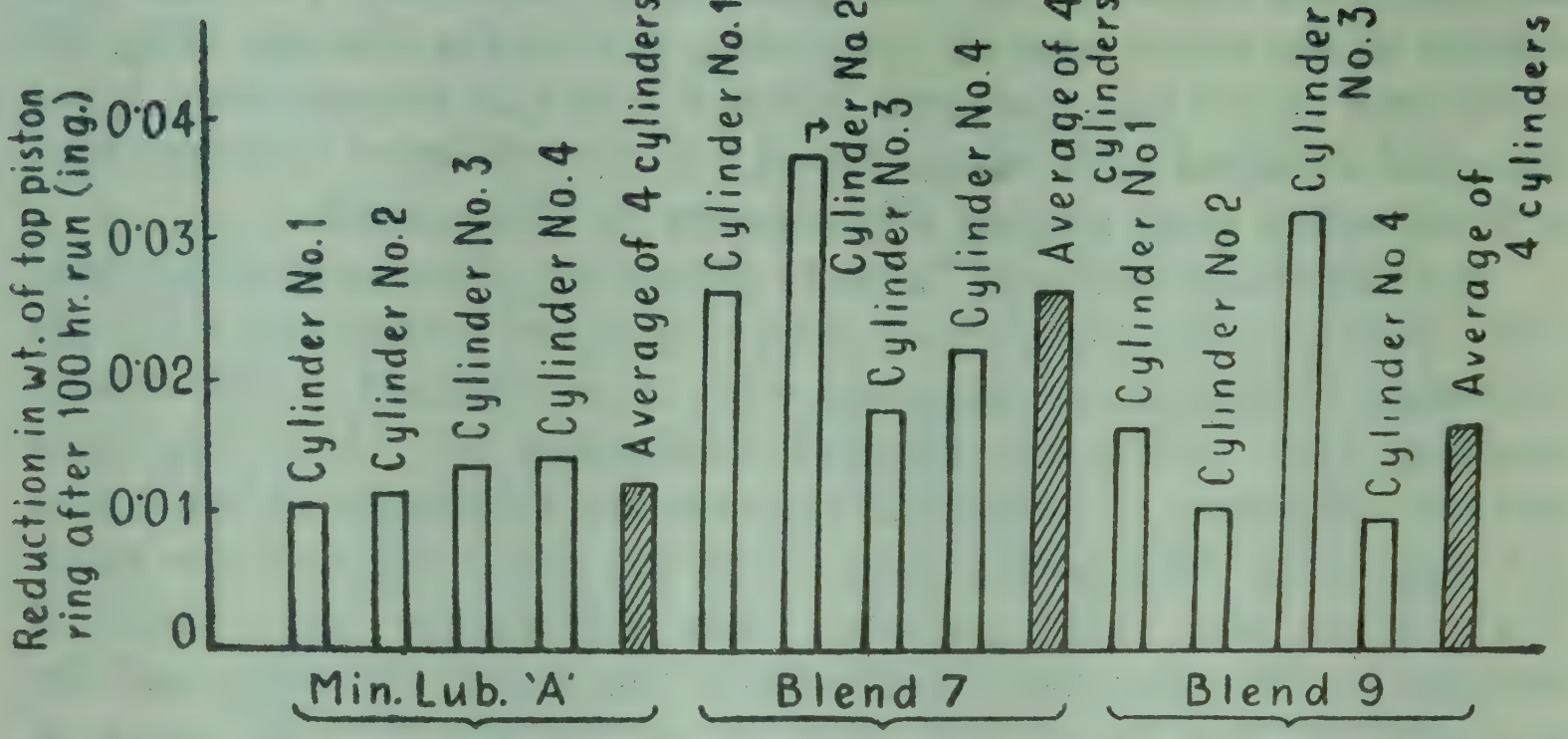


Fig. 28—Graphical representation of loss in weight of top piston after 100 hrs. engine test (Morris Engine)

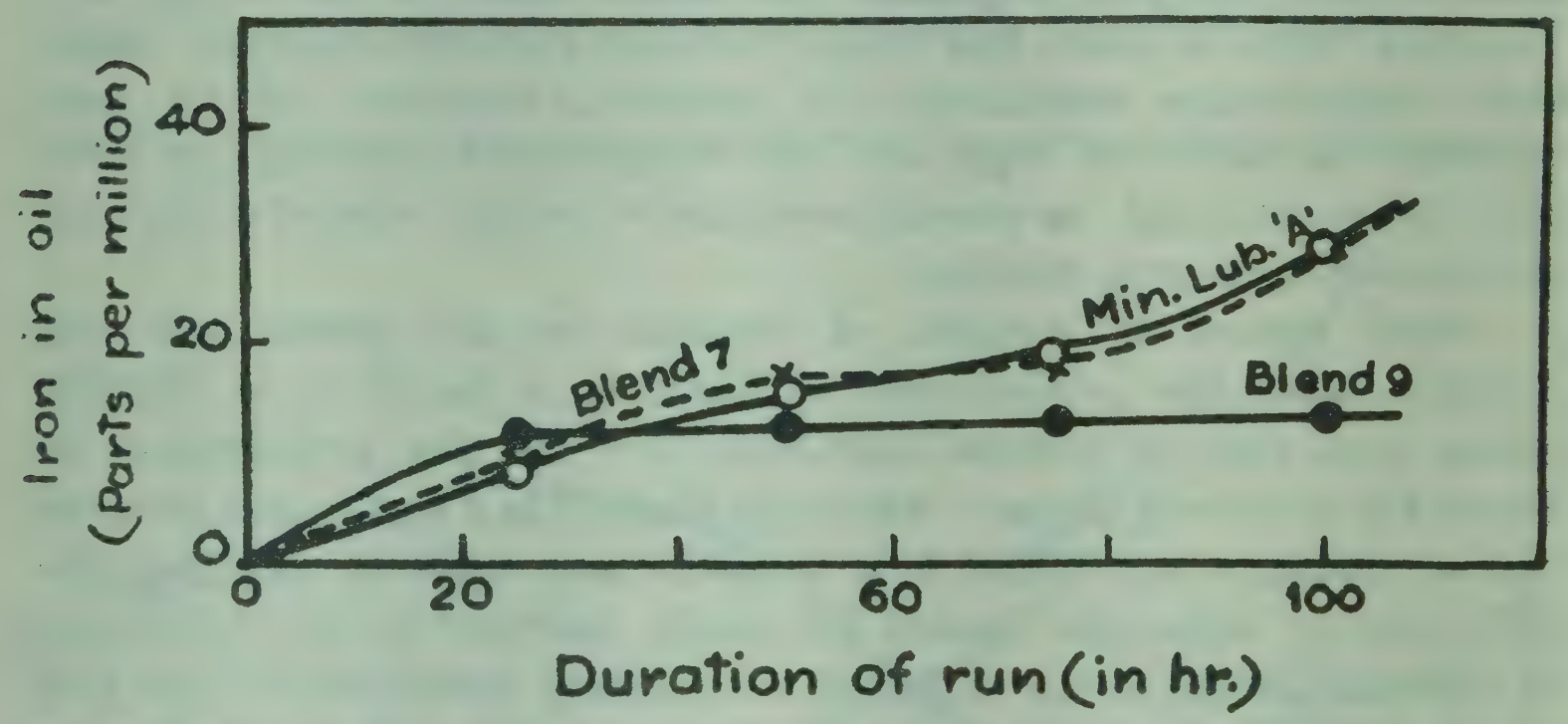


Fig. 29—Change in iron content (in solution) of crank case oil with duration of run (Morris Engine)

blends, but partly also to the difference in the initial viscosities of the two blends (Table 8). The lower initial viscosity of Blend 9 was evidently responsible for more oil going past the piston rings into the combustion space, resulting in more deposits. This is also confirmed by the slightly higher consumption figure in the case of this blend (Table 8).

In respect of deposits on valves and pockets, both the vegetable oil blends, however, proved definitely worse than the mineral oil "A". Although the individual weights of deposits in case of Blend 7 were not determined, it can be safely concluded from the available data that the performance of the two blends was practically identical. It is observed that the amount of deposit decreased with the increase in distance of the valves or their pockets from the oil spray which is located in the valve chamber near the inlet valve of

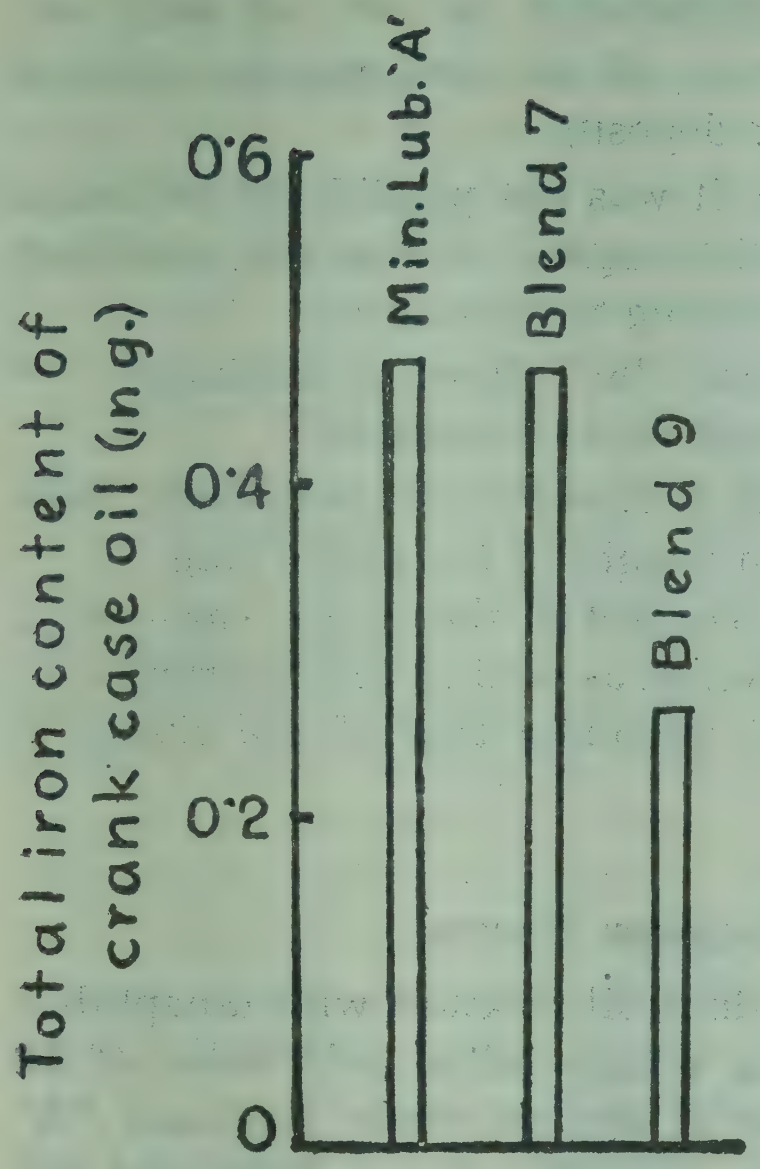


Fig. 30—Graphical representation of total iron content of crank case oil after 100 hrs. engine test (Morris Engine)

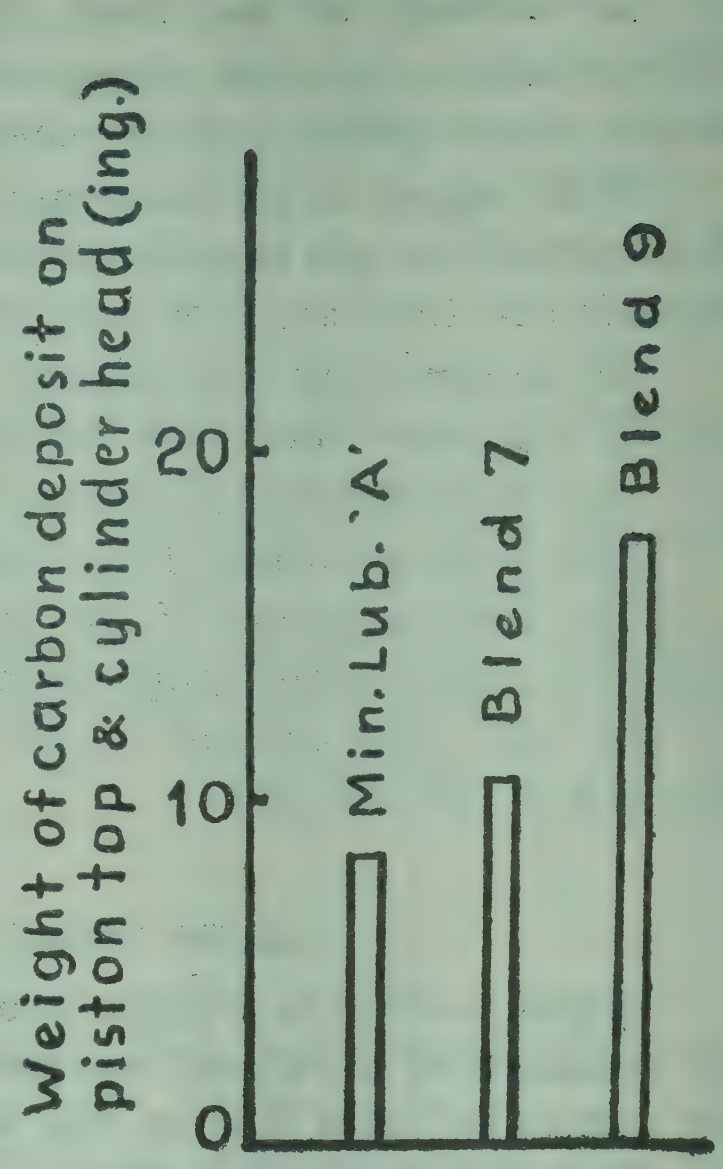


Fig. 31—Graphical representation of wt. of deposit on piston top and cylinder head after 100 hrs. engine test (Morris Engine)

cylinder No. 1 for the lubrication of the valves in their guides. Although it must be admitted that vegetable oils have a definitely greater carbon forming tendency than mineral oils in general, the real explanation for the peculiar manner in which the amount of deposit has progressively decreased from the point of admission of the oil into the valve chamber lies not only in the quality of the oil itself but also in the peculiar design of the particular engine. This point is discussed below.

Discussion

In evaluating the performance of the various blends, it is considered best to confine the discussion to pure vegetable oil blends and to discuss first the results obtained with the various blends as a result of runs in the smaller engine (Lister single cylinder), and subsequently to compare the performance of some of the blends, which have proved satisfactory, with that obtained in the larger unit. It is, however, not necessary to discuss all the data obtained in connection with the various characteristics or engine operation, which have already been briefly dealt with. It is here proposed to judge the comparative merits of various blends from the following points of view :

(1) Change in the main characteristics of the oil such as: (1) viscosity, acid value, sludge content; (2) oil consumption; (3) wear of the engine parts; and (4) carbon deposits.

With regard to oil consumption, it was not possible to determine it accurately in the case of the smaller engine. It was not, therefore, included in the Tables of data pertaining to this unit.

In determining the engine wear the following methods[13, 14, 26] which are now commonly recognized, were employed:

(a) Measurement of the increase in diameter of the cylinder bore

(b) Determination of the loss in weight of top piston ring

(c) Determination of the iron content of the crank case oil at different stages of the progress of the run as well as the determination of the total iron content of the oil including that of the sludge at the end of 100 hrs. run.

Lister Single Cylinder Engine

Blend 3—This is a castor-groundnut oil mixture with α-naphthol. It consisted of unrefined oils having a high initial acid value of 2.5 as compared with 0.10 in the case of the reference lubricant "A" (second standardization run). The viscosity of the blend did not show any appreciable change with engine operation (Table 12). The acid value, which was high to start with, instead of increasing further, showed a slight decrease. The quantity of sludge in the crank case oil after 100 hrs. run was practically 50 per cent more than in the case of the reference lubricant.

With regard to the wear characteristics, the performance of the oil was decidedly inferior to that of the reference lubricant. Although the reduction in weight of top piston ring was only 20 per cent more, the increase in cylinder bore was 0.0005 in. as compared with the negligible change in the case of the run with the reference lubricant, and the total iron content of the crank case oil was nine and a half times that obtained after the standardization run.

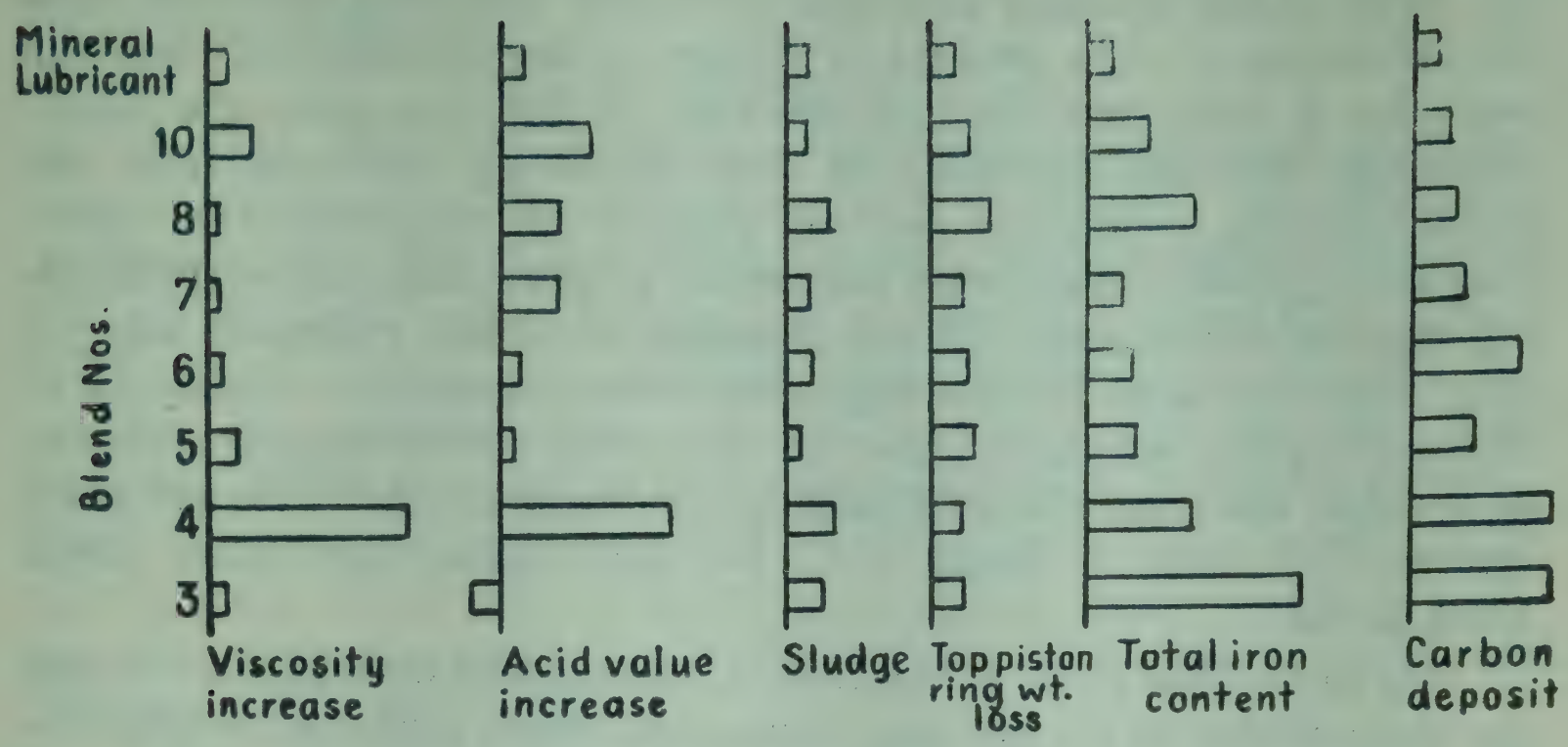
The amount of carbon deposits on the piston top and cylinder head as well as the underside of the piston was also decidedly higher, being 6.0 and 1.18 g. respectively as against 0.6 and 1.0 g. obtained with the reference oil. While, therefore, the change in viscosity and acid value of the blend was quite comparable with the corresponding figures for the reference oil, its performance in other respects, particularly the wear of the engine parts, was definitely worse. The high wear figure, it is supposed, might have been due to the high acid value of the oil, but it must be pointed out that the acid value of an oil is not always a deciding factor in corrosion. The nature of acids is of more importance in this respect than their quantity.

Blend 4—This is identical in composition with Blend 3 but without any stabilizer. It had also the same viscosity and acid value as the latter. It was subjected to engine test primarily with a view to determining the extent to which the presence or absence of a stabilizer affects the changes in characteristics of an oil or influences the engine operation. An examination of Tables 5 and 12 and Figs. 3 and 5 shows that the percentage rise in viscosity was nine times and acid value increase nearly seven and a half times the corresponding values for the reference lubricant, or, compared to Blend 3, the viscosity increase was nearly ten times, while the acid value increase was 2.75 as against a slight decrease in the case of the former blend. The sludge content of the oil was also twice that obtained with the reference oil as against one and a half times in the case of Blend 3. What is most striking is that the wear characteristics of the oil showed up appreciably better than those of Blend 3, whereas the amount of carbon deposit on the piston and cylinder head was practically the same as that obtained with Blend 3. The amount of carbon deposit on the underside of the piston, on the other hand, was considerable, being 13.2 g. as against 1.8 g. in the case of Blend 3 and 1 g. in the case of the reference oil. It should be pointed out that, in spite of the enormous increase in viscosity, there was no appreciable fall in output, nor was there any trouble experienced in the operation of the engine, or undue rise of the equilibrium temperature of the crank case oil or any unusual consumption of petrol. One other point that deserves special mention is the fact that in spite of the final acid value of the blend being twice that of Blend 3, the amount of iron removed from the engine was less than half of that removed by the latter under similar operating conditions. It appears, therefore, that the acidic character of the stabilizer (α-naphthol) was responsible for the removal of a large quantity of iron from the engine parts.

Blend 5—The composition of this blend was the same as that of Blend 3 except that its acid value was considerably reduced by refining, which left a small percentage (0.11 per cent) of residual soap. It is clear from Tables 5, 6 and 12 and Figs. 3-7, 13-15 and 32, that the reduction of acid value of the blend caused a considerable improvement over Blend 3 in practically all respects, except for a slightly greater loss of weight of the top piston ring. Compared with the reference lubricant, its performance was appreciably superior in respect of the acid value increase and the quantity of sludge and carbon deposits on piston top and cylinder head. The percentage increase of viscosity, however, was one and a half times that obtained with the reference oil. With regard to wear, although, the cylinder bore showed a negligible change in dimension, the loss of weight of the top piston ring and the total quantity of iron removed by the

TABLE 12—Summary of changes in characteristics of oil blends after 100 hrs. run (Lister Set)

Blend	Composition of blend	Parts	Viscosity increase %		Acid value increase %		Increase in Conradson carbon residue		Amount of sludge		Reduction in wt. of top piston ring		Total iron content		Cylinder wear (in.)	Wt. of carbon deposit on piston top and cylinder head	
			Actual	Ratio	Actual	Ratio	Actual	Ratio	Actual (g.)	Ratio	Actual (g.)	Ratio	Actual (g.)	Ratio		Actual (g.)	Ratio
3	Castor oil ..	60															
	Groundnut oil ..	40	21.4	1.0	—0.4	..	0.59	2.0	1.64	1.5	0.0353	1.2	0.956	9.5	0.0005	3.2	6.0
	α-Naphthol ..	1															
4	Castor oil ..	60															
	Groundnut oil ..	40	216.2	9.1	2.75	7.6	1.20	4.0	2.39	2.1	0.0347	1.2	0.443	4.4	0.0002	3.3	6.0
	No stabilizer																
5	Castor oil ..	60															
	Groundnut oil ..	40	31.4	1.5	0.13	0.4	0.33	1.1	0.30	0.7	0.0500	1.8	0.226	2.2	Negligible	1.4	2.5
	α-Naphthol ..	1															
	Soap ..	0.117															
Mineral lubricant "A".	..		21.3	1	0.36	1	0.30	1	1.12	1	0.0283	1	0.101	1	do.	0.55	1
6	Castor oil ..	60															
	Groundnut oil ..	40	20.2	0.9	0.32	0.9	0.36	1.2	1.32	1.2	0.0434	1.5	0.195	1.9	do.	2.5	4.5
	α-Naphthol ..	1															
	Soap ..	0.0195															
7	Castor oil ..	60															
	Groundnut oil ..	40	12.4	0.6	0.84	2.3	0.28	0.9	1.06	1.0	0.0351	1.2	0.149	1.5	do.	1.3	2.4
	α-Naphthylamine	1															
8	Castor oil ..	60															
	Groundnut oil ..	40	11.8	0.6	0.93	2.6	0.38	1.3	1.94	1.7	0.0680	2.4	0.497	4.9	0.003	0.98	1.8
	α-Naphthylamine	1															
	Chromium oleate	0.1															
10	Castor oil ..	50															
	Rape oil ..	50	45.7	2.1	1.22	3.4	1.12	3.7	0.86	0.8	0.0460	1.6	0.270	2.7	Negligible	0.77	1.4
	β-Naphthylamine	0.5															
	Diphenylamine	0.5															



.Fig. 32—Graphical representation of changes (ratios) in principal characteristics

blend were practically 75 per cent and 100 per cent respectively more than in the case of the reference oil. With all this improvement, however, the blend showed a weak point, i.e. it caused the sticking of the top piston ring, which was found imbedded in a semi-solid mass of deposit. The reduction of acid value cannot possibly explain this phenomenon, and it is at the same time very difficult to say whether the presence of the residual soap left as a result of refining was at least partly responsible for this state of things, or whether it was purely accidental.

Blend 6—This is identical in composition with Blend 5 except that its soap content was appreciably reduced with a view to determining its influence on the engine operation and judging whether it becomes free from the weak points, revealed by Blend 5. An examination of Tables 5, 6 and 12 and Fig. 32 indicates that this blend showed improvement in some respects (viscosity increase and the quantity of iron removed) and deterioration in others, particularly, in respect of the carbon deposits, which were appreciably higher than in the case of Blend 5. The only marked beneficial effect which it seemed to produce was the freedom from gummy deposits in piston ring grooves and the ring sticking tendency produced by Blend 5.

Blend 7—This is a castor-groundnut oil blend of the same percentage composition as the preceding blends but was stabilized with α-naphthylamine instead of α-naphthol. Results of engine tests recorded in Tables 5, 6, 11 and Figs. 3-7, 13-15 and 32 show that this blend exhibited an all-round improvement except with regard to acid value increase, and proved to be the best of all the vegetable oil blends so far tried. It is interesting to note that the changes in the various properties of the oils were brought about within practically the first 25 hrs. run. The viscosity change was

the least so far attained and was even less than that obtained with the reference oil; the amount of sludge in the oil after 100 hrs. run was also a little less than in the case of the run with the latter. Although the total quantity of iron (0.149 g.) removed from the engine and the weights of deposits (1.82 g.) on the piston top, underside and cylinder head were somewhat greater than the corresponding figures (0.101 and 1.55 g.) obtained with the reference oil, yet they were the least for the vegetable oils tried so far. It may be of interest to point out that in spite of the comparatively large increase in acid value, the wear characteristics of the blend proved to be decidedly superior to those of Blend 6 or, for that matter, any other blend tried so far.

Blend 8—This blend is identical in composition with Blend 7 except for the addition of 0.1 per cent chromium oleate intended to improve the service characteristics of Blend 7 further, particularly with regard to carbon deposits. It is clear from Tables 5, 6 and Fig. 32 that, although the viscosity and acid value increase remained practically the same as those in the case of Blend 7, it had deteriorated practically in all other respects with the important exception of carbon deposits, which were the least so far obtained with the blends. Although, therefore, the expectation of reduced carbon deposits was fulfilled, the excessive wear as shown by the reduction in weight of top piston ring and the total amount of iron in crank case oil rules out the blend when compared with Blend 7.

Blend 10—This is a castor-rape oil mixture of the same percentage composition as Blend 9, but was stabilized with equal parts of β-naphthylamine and diphenylamine. An examination of Tables 5, 6, 12 and Fig. 32 shows that with the exception of sludge content and carbon deposits, which showed an appreciable improvement in comparison with Blend 7, the blend showed a marked deterioration.

The blend, however, was a distinct improvement on Blend 8, with regard to the formation of sludge, carbon deposits and wear of the engine parts, although the viscosity and acid value increases were appreciably higher in the case of the former. Comparing the two blends, it may be stated that, generally speaking, Blend 8 showed better stability, but worse wear characteristics, whereas Blend 10 showed better wear characteristics and worse stability. One other interesting feature which may be pointed out in this connection, is that, while Blend 8 showed a less viscosity increase and a greater sludge content, Blend 10 showed a greater viscosity increase and a lesser amount of sludge. The explanation of this phenomenon appears to lie in the fact that in the former, the polymerized and cracked products were less soluble, thus depositing solid or semi-solid residue in the crank case oil, whereas in the latter these products were more

soluble giving rise to increased viscosity and deposition of less solid product or sludge.

Morris Industrial Engine

Blend 7—The various points of interest regarding the performance of this blend in the Morris engine have already been discussed in detail under the Tables presenting the various data obtained as a result of engine tests. It may now be generally stated that in spite of the blend showing a somewhat greater increase in viscosity and acidity, the frictional losses in the bearing parts and the total quantity of iron removed from the engine parts were similar to those obtained with the reference oil. The loss of weights sustained by the top rings varied between 0.0177 and 0.0387 g., while the corresponding figures obtained as a result of run with the reference oil varied between 0.0110 and 0.0150 g.

It may also be pointed out that while the bores of two of the cylinders showed an increase of 0.0002 in. and 0.0005 in. respectively, none of the cylinders showed any measurable change after 100 hrs. run with the reference oil.

The blend, however, was definitely superior to the reference oil as regards the development of sludge or the consumption of oil.

As regards the deposits on the piston top and the cylinder head, it is clear from Table 11 that the blend produced a slightly larger amount of deposits than the reference oil. One other important point that deserves to be considered and has already been discussed at some length is the formation of considerable gummy deposits on the shoulder and part of the stem of the inlet valves and their pockets and the absolute freedom of deposits on all the exhaust valves or their pockets. What was rather interesting was that the amount of deposit generally decreased from one end of the valve chamber to the other, so that the amount of deposit was at a maximum in the case of the inlet valve of cylinder No. 1 and at a minimum or practically nil in the case of the inlet valve of cylinder No. 4. This at once leads to the conclusion that the oil spray being located close to cylinder No. 1 was delivering an unnecessarily large quantity of oil to the valves adjacent to it. The very fact that there was no trouble regarding the lubrication of the valves, of, say, cylinders Nos. 3 and 4, in their guides, affords an additional proof of this assumption. It should, however, be pointed out that this particular method of lubricating the valve stems is peculiar to this make of engine only; in most engines, the only means of lubricating the valves in their guides is a fine spray of oil carried into the valve chamber from the crank case, so that all the valves get the proper and an approximately equal amount of oil. It may also be pointed out that in the case of run with the reference oil also, the inlet valves showed an appreciable deposit, which, however, was not weighed.

In the light of the above explanation, it is not unlikely that the vegetable oil blends will be free from this defect when used in other engines. The reason for the vegetable oil blends giving more deposit on the inlet valves and none on the exhaust valves appears to be that the temperature of the latter is very much higher and any oil finding its way into the exhaust valve pockets burns out completely, while the temperature of the inlet valves is not high enough for complete combustion nor low enough to retard effectively such reactions as polymerization, decomposition, etc. It is, however, expected that it is possible to eliminate this undesirable deposit on the inlet valve by modifying the method of lubricating the valve chamber or controlling the temperature of the intake mixture.

Briefly stated, the blend was found to be superior to the reference oil in respect of the sludge content and oil consumption, similar to it in respect of the total iron removed from the engine parts and the cylinder wear, and somewhat inferior in respect of viscosity and acid value increase as well as the loss of weight of top piston ring and carbon deposits.

As the quantity of acids cannot be considered to be a criterion of the deterioration of an oil unless it be of such a nature as to cause excessive corrosion of the parts with which it comes in contact, and as the iron content of the crank case oil and the cylinder bore wear were similar for the blend as well as for the reference oil, the comparatively high acidity of the used oil cannot be considered to be a serious defect. The viscosity increase was also not such as to cause excessive frictional losses as determined by the motoring tests at intervals. The carbon deposits were appreciably more, but in no way excessive. Except, therefore, for an appreciably greater loss of weights of some of the top piston rings, and the tendency of accumulation of gummy deposits on the inlet valve shoulders, which are undesirable, if considerable in amount, the blend, on the whole, compared favourably with the reference oil when subjected to engine tests under similar operating conditions.

Blend 9—This is a castor-rape oil mixture in equal proportions, treated with α-naphthylamine. In view of the satisfactory behaviour of the rape oil with α-naphthylamine in the oxidation test, it was decided to replace the groundnut oil in Blend 7 by rape oil with a view to improving the performance still further. The percentage composition of this blend, for reasons given before, was adjusted to give a lower initial viscosity (109 c.s. at 100°F.) as compared with 128.6 c.s. in the case of the vegetable oil Blend 7 and 122.1 c.s. in the case of the reference lubricant.

An examination of Tables 8, 9 and 10 and Figs. 18-22 and 27-31 shows that the substitution of rape oil for groundnut oil

caused an all round improvement in the performance of the blend over blend 7 except in respect of oil consumption and carbon deposits on the piston top and cylinder head which showed a slight increase. The improvement in the two important respects of sludge and iron content of the crank case oil after 100 hrs. run was remarkable in that in these respects the blend far excelled the reference lubricant. The loss of weight of the top piston rings, with the exception of one, compared favourably with that obtained with the reference oil. The cylinder bores also did not show any measurable change in dimension except in the case of one which showed an increase of 0.0003 in The improvement in respect of viscosity, acid value and carbon residue was also quite appreciable. It may, however, be pointed out that in view of the wear and friction characteristics of the blend being either superior or similar to those of the reference oil, the slightly higher figures for acid value or viscosity cannot be considered to constitute a serious defect of the oil.

The slightly higher increase in oil consumption can be definitely attributed to the lower initial viscosity of the blend, as the other factors governing it, namely, engine design, speed, engine changes due to wear (which was negligible as the two blends were run consecutively) or volatility (both were fixed oils) remained practically constant. The increased carbon deposits on piston top, etc., as explained previously, might also be attributed to this fact.

The deposits on the shoulder and stem of the inlet valves were of the same magnitude (Table 11) as those in the case of run with the previous blend, but rather more than that obtained with the reference oil. The possible cause of their formation in decreasing amounts from the point of admission of oil into the valve chamber and the possible methods of prevention have already been discussed under Blend 7.

Except for the formation of deposits which can be reduced by one method or another, as pointed out before, the performance of the blend is more or less similar to that of the reference lubricant "A" and with regard to sludging and the amount of iron removed from the engine parts, its performance was decidedly superior.

It may, therefore, be stated that Blends 7 and 9 have proved quite satisfactory as lubricants for petrol engines of sizes up to about 16 h.p. Blend 9 could further be improved by adjusting its viscosity to a slightly higher figure in the neighbourhood of 120-130 c.s., which can be done by slightly increasing the proportion of castor oil in the blend.

Finally, it is desirable to find out if there exists any correlation between the viscosity increase obtained as a result of the modified

TABLE 13—Comparative figures for viscosity increase as a result of modified Air Ministry Oxidation Test and 100 hrs. engine test (Lister Set)

Blend	Viscosity increase ratio at 100°F.	% increase in viscosity at 100°F.
Mineral lubricant "A"	1.1	26.1
Blend 1	5.5	15.1
Blend 2	5.3	27.0
Blend 3	3.5	25.1
Blend 4	7.3	270.9
Blend 5	3.8	30.8
Blend 6	3.9	26.0
Blend 7	4.4	16.6
Blend 8	4.0	14.6
Blend 10	4.8	53.2

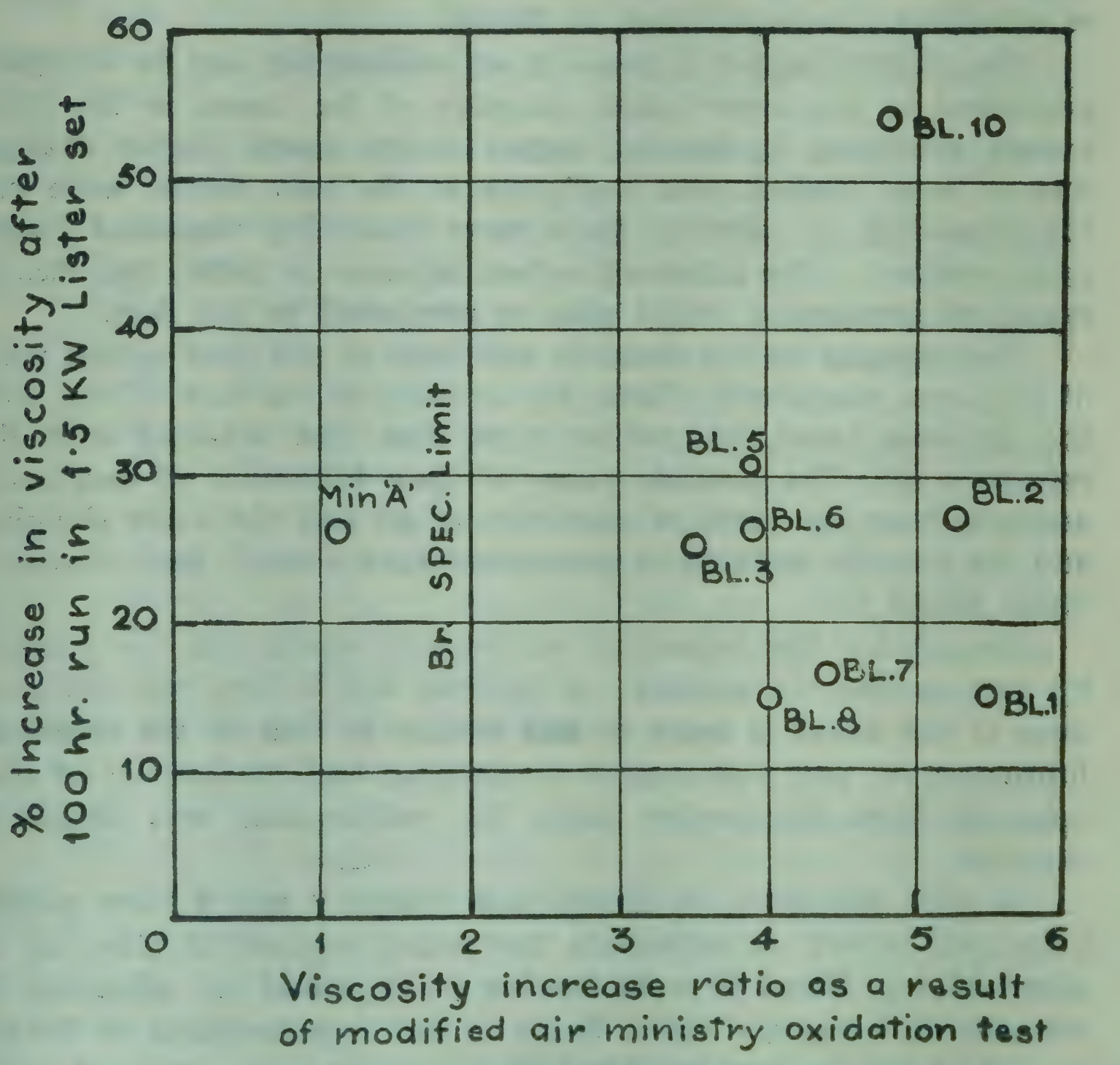


Fig. 33—Comparison of viscosity increases obtained by Air Ministry Oxidation Test and engine tests

Air Ministry Oxidation Test and that obtained as a result of engine operation, so as to justify the selection or grading of lubricating oils merely on the basis of Air Ministry Oxidation Test, or whether the vegetable oils differ from the mineral oils in this respect. To facilitate examination of the degree of correlation, if any, the figures for viscosity increase ratios at 100°F. as a result of the modified Air Ministry Oxidation Test and the percentage increase in viscosity of the various blends at the same temperature after 100 hrs. operation in Lister engine have been collected together in Table 13 and plotted in Fig. 33.

It is clear from Table 13 that there does not appear to exist any definite correlation between the viscosity increase figures obtained as a result of Air Ministry Oxidation Test, and actual engine tests on the different vegetable oil blends, which confirms the observations of Hanson & Egerton[23] as also those of Mardles & Ramsbottom[24] about mineral oils in general. They have stressed the necessity of actual engine tests as the final criterion of the suitability of a lubricant for I. C. engines. Pye[25] also acknowledges the limited value of the British Air Ministry Oxidation Test in the following terms: "A check on the chemical stability of an oil against oxidation at 200°C. and decomposition at the higher temperature is aimed at and to some extent achieved. Undoubtedly there are examples of oils which would fail to meet the specification requirement and yet might stand up excellently during prolonged test in service."

The findings of Pye are sufficiently corroborated by the results of tests (Table 13) on various blends of vegetable oils obtained in these investigations. In spite of the fact that practically all the blends failed to comply with the requirements of the Air Ministry Specification as regards the viscosity increase ratio, some of the blends stood up excellently under engine operating conditions in both small and medium power engines.

Summary

Based on the results of investigations given in Part I, a number of blends of different oils having the requisite viscosity characteristics for use as lubricants in internal combustion engines was developed.

The engine equipment consisted of a 3 h.p. single cylinder petrol engine, and a 16 h.p. 4-cylinder petrol engine, both coupled to electric generators for the purpose of loading. Both these engines, particularly the larger one, were suitably modified and a number of test accessories was provided to obtain adequate control of the various operating conditions, such as power output, speed, cooling water temperature, intake mixture temperature, oil pressure, ignition advance, etc.

Preliminary tests of 100 hrs. duration were carried out in the small engine on 2 vegetable-mineral oil blends and 7 vegetable oil blends. Of these, the blends that were found to be highly satisfactory were tried in the large engine for 100 hrs. For comparison, runs were also made in both engines with two well known makes of mineral oils. Oil samples were withdrawn from the crank case at intervals during the run and at the end of the run; these were thoroughly examined for the various chemico-physical changes, sludge production, iron contamination, etc. Engine parts were carefully measured to an accuracy of ± 0.0001 in. before and after the runs, with a view to determining wear. The wear of the top piston ring was determined by weighing, with the same end in view. Carbonaceous and other deposits formed on various parts of the engines were carefully observed and recorded.

After a thorough examination of all the data collected it was found that satisfactory vegetable oil blends could be prepared which would compare favourably with mineral oil lubricants in almost all respects, with the exception perhaps of the carbon deposit on piston top, etc., which was slightly more in the case of vegetable oil blends than in the case of mineral oils. But this is not considered a serious drawback, as it does not interfere with the smooth operation of the engine. One of the vegetable oil blends tried actually proved superior to mineral oil in respect of sludge formation and iron dissolution from engine parts. Furthermore, two blends also gave less increase in viscosity than the reference mineral oil.

As a result of these investigations, two types of blends can be confidently suggested for use in medium size internal combustion engines, namely, castor oil-rape oil blends and castor oil-groundnut oil blends. It is important that the oils before blending be thoroughly refined and freed from alkali soaps. For a good stabilizer for these blends, α-naphthylamine is recommended which should be used in proportion of not less than 1 per cent. The proportions of the two oils to be used to form the blend will depend on the viscosity of the lubricant required. Generally, for medium size engines requiring a medium grade of oil, about 60-55 per cent of castor oil to 40-45 per cent of rape or groundnut oil would be appropriate.

Acknowledgment

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APPENDIX

Abstracts of papers on the Use of Vegetable Oils as Lubricants in Internal Combustion Engines, published after 1942

I. The possibility of utilizing taramira (*Eruca sativa*) oil as a lubricating oil for internal combustion engines has been investigated and compared with rape oil. The following are the salient results of the investigation :

(1) taramira oil is better than rape oil in its viscosity-temperature relationship.

(2) α-naphthol is the best anti-oxidant for taramira oil when tested as per British Air Ministry Oxidation Test as modified by Aggarwal & Verman.

(3) 40 : 60 blend of taramira oil and castor oil shows more or less the same degree of stability as rape oil in a similar blend. In this case both α-naphthol and basic stabilizers are effective [Nanda *et al., J. Indian chem. Soc. Industr. Edn.,* **10** (1947), 131].

II. The properties of partially hydrogenated argemone oils from the point of view of their utilization as lubricating oil for internal combustion engines have been studied. The following are the conclusions :

(1) Partially hydrogenated argemone oil of iodine value 93.8 with 1% α-naphthol and α-naphthylamine as stabilizers resembles blends of castor oil with other vegetable oils and merits trial as lubricant [Nanda & Mathur, *J. Indian chem. Soc. Industr. Edn.,* **10** (1947), 143].

III. Studies on the utilization of non-edible oils from the seeds of *Calophyllum inophyllum* (domba), *Pongamia glabra* (hongay) and *Bassia longifolia* (mohua) as lubricants have recently been made. All these oils have the same viscosity at 140°F. (163 sec.); hongay oil maintains this value up to about 282°F. which is the crank case temperature for internal combustion engines, while in the other two it gradually falls till 180°F. These oils are not so good from the point of carbon residue and gumming. The Conradson carbon value for domba, hongay and mohua oils are 2.61, 1.65 and 0.45 per cent respectively. The oxidation tests as per A.S.T.M. standards show that anti-oxidants stabilise the oils. Organic stabilisers like α-napthol, β-naphthol and naphthylamine are effective, the last one being the best. Oiliness was evaluated by finding *P/W*

where P is the power required to move a slider of weight W across a surface (mild steel on brass and cementite steel on brass) with a film of oil. Of the three oils, mohua oil has the greatest oiliness. Oils refined by treating them with barium hydroxide to neutralize their acid content and filtering exhibit higher oiliness, but viscosity changes are relatively small. Raw and neutral oils when subjected to *Voltol* treatment, suffer an increase in viscosity and decrease in iodine value. The Conradson carbon value is reduced and the oiliness is greatly improved by this method. The studies point to the following order of preference for the three oils examined for lubricating properties: mohua, hongay and domba. The conclusions are: domba oil may be used for ordinary purposes of lubricating general shafting and other exposed running parts of machinery, while the other two oils could be used after neutralisation and subjection to the *Voltol* process for bearings of small gas engines, enclosed gears and bearing engines having forced and splashed systems of lubrication [Srikantan & Thiagarajan, *J. Indian chem. Soc. Industr. Edn.*, **13** (1950), 163, 201, 210, 219, 227].

IV. Dhiren Ghosh and Mukherji have studied the lubricating properties of castor, groundnut and mustard oils and the effect of urea and 1:8 dinitronaphthalein as anti-oxidants [*Indian Soap. J.*, **11** (1945), 43].

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